FIELD EXCURSION 2, GUIDEBOOK

GEOLOGY OF THE SOUTHERN APPALACHIAN MOUNTAINS

12-17, August

By: D. E. Pride, and R. O. Utgard

SIXTH GONDWANA SYMPOSIUM
19-23 August, 1985

The Ohio State University
Columbus, Ohio

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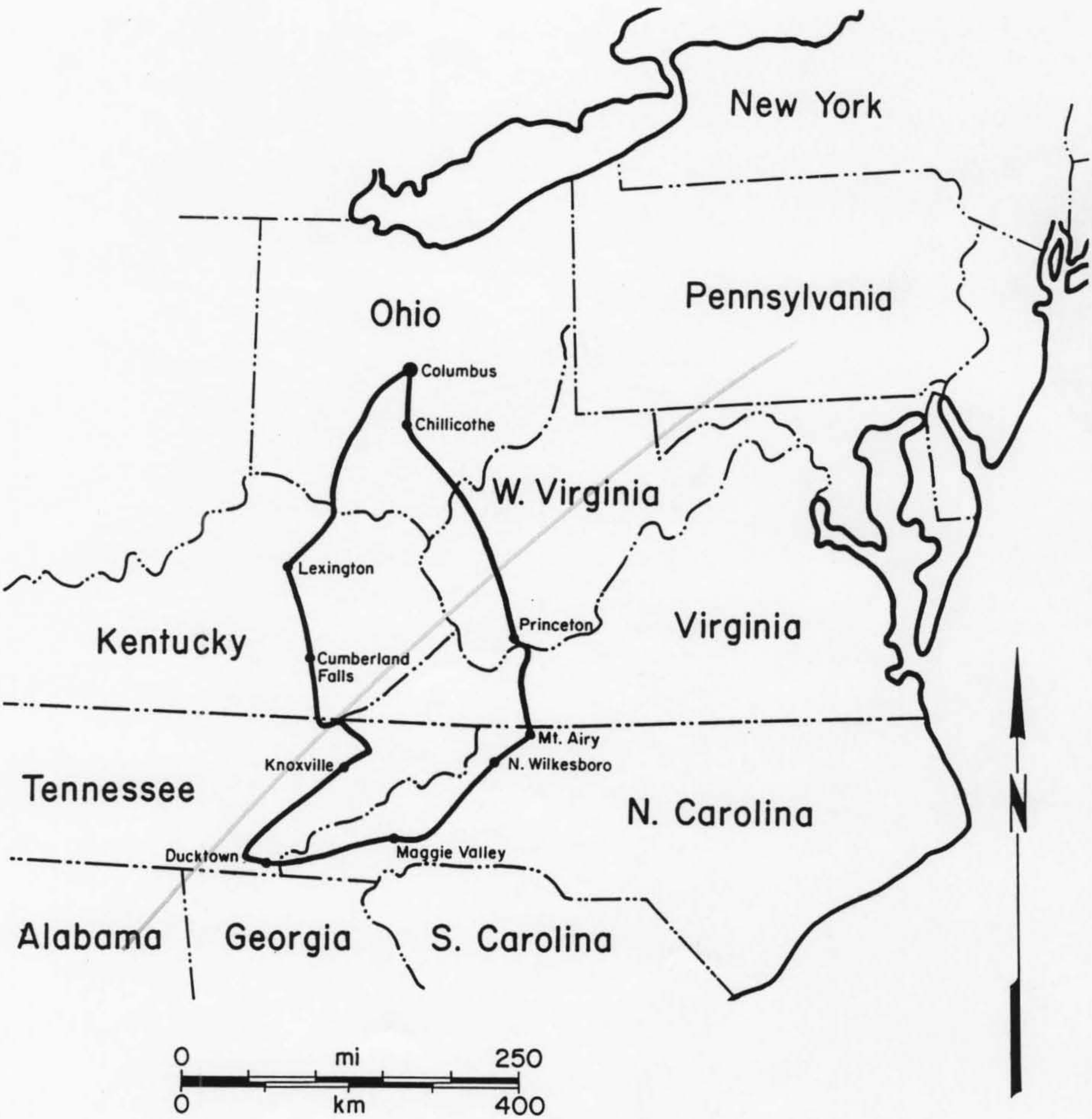

TRIP ROUTE - FIELD EXCURSION 2, SOUTHERN APPALACHIANS

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INTRODUCTION

This field trip will cover about 1400 miles (2254 km) in six days and will take us into six physiographic provinces of the United States (Figure 1 and Table I). We will see considerable stratigraphic and structural variation, and we will visit igneous, sedimentary, and metamorphic terranes. Rocks ranging in age from Precambrian through Permian, as well as Quaternary glacial deposits, will be encountered. Although our primary objective will be the general geology of the region, several of the stops will focus on economic geology.

* * * * * * *

- Day 1 -

Columbus, Ohio

to

Princeton, West Virginia

± 275 miles (443 km)

We will start the day on Devonian bedrock in glaciated central Ohio and will cross till plains of the Central Lowlands Province (figs. 2 and 4). Glacial features are present and we will examine evidence of the pre-glacial Teays drainage system (Fig. 3). Much of the day will be spent crossing Paleozoic beds of the Appalachian Plateaus Province. A visit will be made to a large coal-burning electrical generating plant.

Major Stops

1. Glacial boundary and Teays drainage (figs. 2 and 3)
2. Pennsylvanian/Mississippian regional unconformity
3. Permian/Pennsylvanian unconformity
4. John E. Amos electrical generating plant
5. Cyclic coal deposits of the Pennsylvanian (Fig. 6)
6. Weathering features of Pennsylvanian and Mississippian rocks

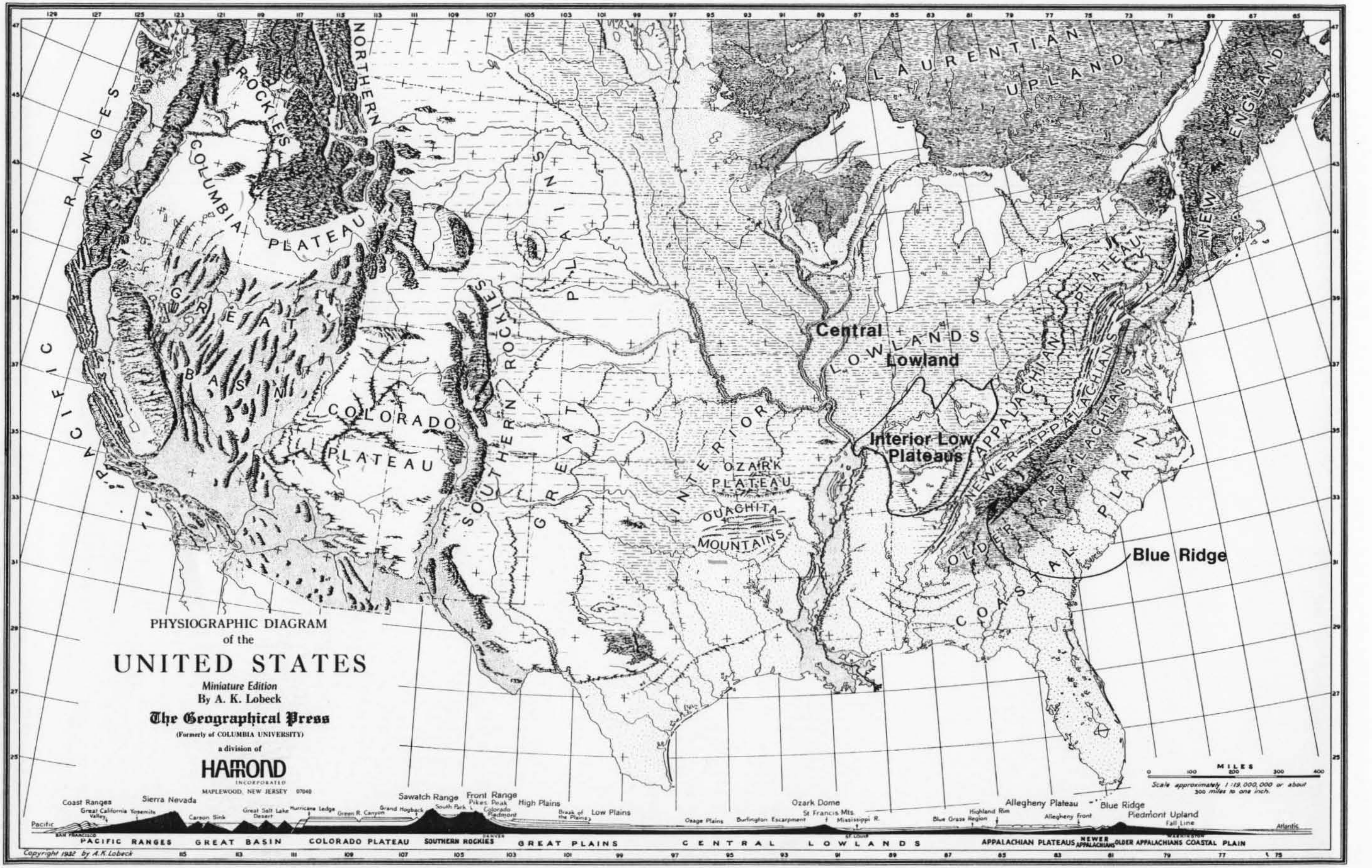


Figure 1. Physiographic diagram of the United States.
(modified)

Table I.
Physiographic areas of the United States
(modified from Bloom, 1978)[1].

Division	Province	Section Visited
Laurentian Upland	1. Superior	
Atlantic Plain	2. Continental Shelf	
	3. Coastal Plain	
Appalachian Highlands	* 4. Piedmont[(a)]	Piedmont Upland
	* 5. Blue Ridge	Southern Section
	* 6. Ridge and Valley[(b)]	Tennessee Section
	7. St. Lawrence Valley	
	* 8. Appalachian Plateaus	Allegheny/Cumberland
	9. New England	
	10. Adirondack	
Interior Plains	*11. Interior Low Plateaus	Bluegrass or Lexington Plain Highland Rim
	*12. Central Lowland	Till Plain
	13. Great Plains	
Interior Highlands	14. Ozark Plateaus	
	15. Ouachita	
Rocky Mountain System	16. Southern Rockies	
	17. Wyoming Basin	
	18. Middle Rockies	
	19. Northern Rockies	
Intermontane Plateaus	20. Columbia Plateaus	
	21. Colorado Plateaus	
	22. Basin and Range	
Pacific Mountain System	23. Cascade-Sierra Mts	
	24. Pacific Border	
	25. Lower California	

* Provinces visited on field trip

Note: On Figure 1, provinces are shown as:

(a) Older Appalachians
(b) Newer Appalachians

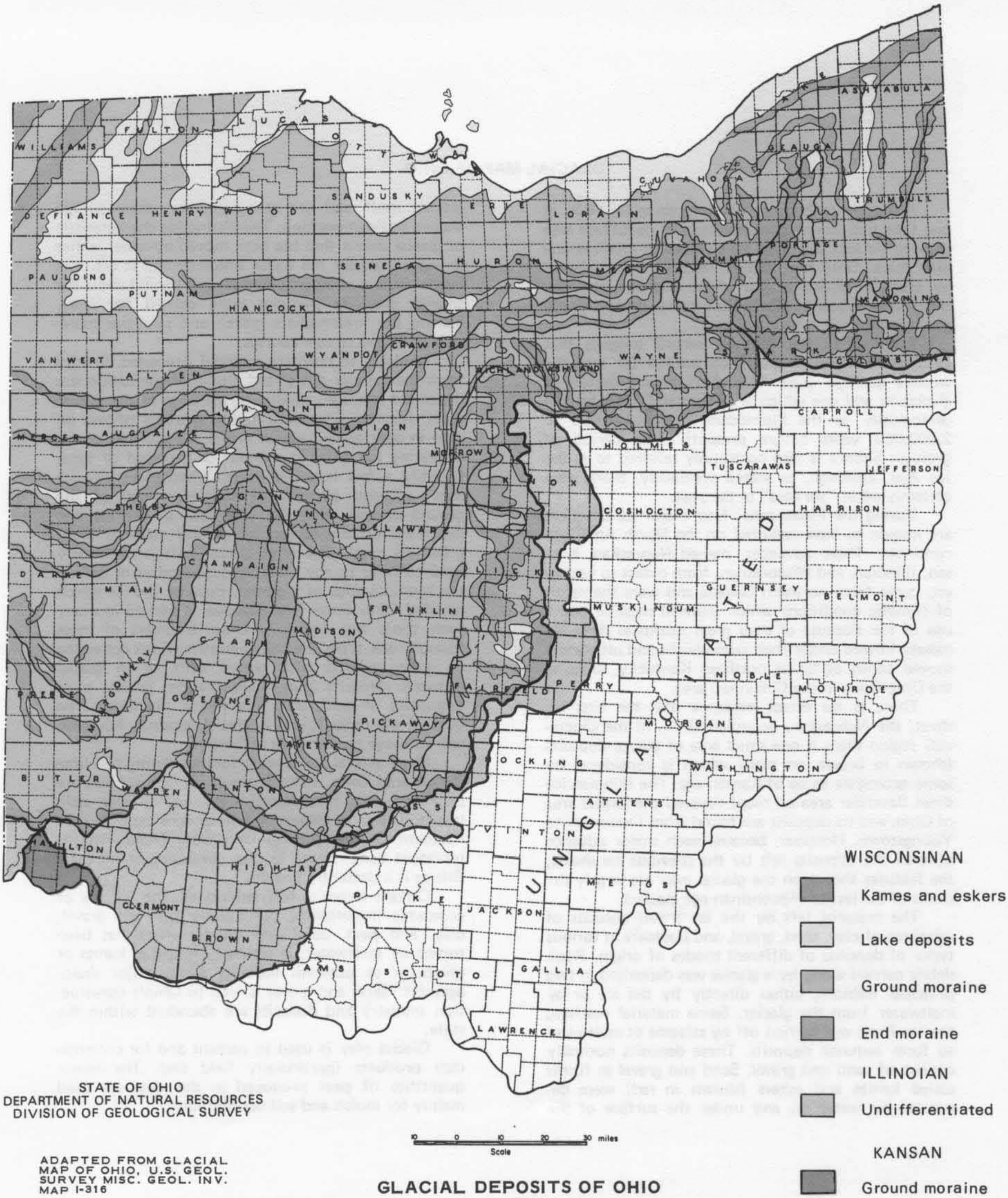
(1) Bloom, A.L., 1978, Geomorphology - A systematic analysis of Late Cenozoic landforms, Prentice-Hall, Englewood Cliffs, N.J., 510 p.

TEAYS DRAINAGE

Prior to Pleistocene glaciations in this area, the drainage pattern was much different than it is today. Much of the area that is drained by the Ohio River today was drained by the ancient Teays River. The Teays was a thousand miles (1600 km) long, and had its source in the Blue Ridge near Blowing Rock, North Carolina (Fig. 3). From there it followed a northerly course across Virginia and into West Virginia as far as Charleston and St. Albans, along the present courses of the New and Kanawha rivers. From St. Albans it continued west to Huntington, West Virginia, then northwestward along a stretch of the present Ohio River toward Portsmouth, Ohio, where it "swerved" northward to Chillicothe, Ohio. The Teays then flowed to the northwest across Ohio to near Fort Wayne, Indiana, from where it proceeded westward across Indiana and Illinois as far as the present Illinois River valley (Fig. 3). The tributary Mississippi River joined it there, and the Teays flowed to the south and entered an arm of the Gulf of Mexico, which at that time extended up what is now the lower Mississippi River Valley as far as southern Illinois.

With the southward spread of glaciers during Pleistocene time the entire lower half of the Teays River system from Chillicothe, Ohio to its mouth in southern Illinois was covered by ice. Glacial outwash and till filled valleys of the system and preserved them in the subsurface. The upper half of the Teays was blocked by an ice front near Chillicothe. Water of the river was impounded into an immense lake that occupied the Teays River valley and backed up into the lower valleys of tributary streams in southern Ohio, Kentucky, and West Virginia. The water level in the lake rose until it found an overflow point near Portsmouth, Ohio. The new drainage course along and to the south of the ice front became established as the lower part of the present Ohio River.

The upper Teays River from St. Albans, West Virginia to its headwaters occupied what is now essentially the Kanawha-New River drainage system. The New River is unique in that it is the only stream that flows directly across the Ridge and Valley and the Appalachian Plateaus Province. The New River is perhaps the oldest river in the eastern United States, possibly dating to well before Tertiary time. It generally is concluded that the New River (upper Teays) already was flowing in its present course when Ridge and Valley folding and thrusting and Appalachian Plateau uplift occurred. Evidence for this is seen in the present course of the New River as it cuts through deep water gaps in the Ridge and Valley Province, and through a deeply incised gorge with entrenched meanders as it crosses the Appalachian Plateaus Province.



GLACIAL DEPOSITS OF OHIO

Figure 2.

References (Teays drainage)

Fridley, H.M., 1950, The geomorphic history of the New-Kanawha River system: W.Va. Geol. & Econ. Survey, R.I. No. 7, 12 p.

Janssen, R.E., 1952, The history of a river: Scientific American, v. 186, no. 6, p. 74-80.

Rhodehamel, E.C. and Carlston, C.W., 1963, Geologic history of the Teays Valley in West Virginia: G.S.A. Bull, vol. 74, p. 251-274.

Thornbury, W.D., 1965, Regional Geomorphology of the United States: Wiley, New York, 609 p.

The Southern Appalachians are made up of four major physiographic or geomorphic provinces, all of which trend in a southwest to northeast direction. The provinces are from northwest to southeast: the Appalachian Plateaus, the Ridge and Valley, the Blue Ridge, and the Piedmont (Fig. 1 and Table I).

APPALACHIAN PLATEAU

The first of the Southern Appalachian provinces that we will encounter is the Appalachian Plateaus province. This province extends from northwestern New York State to the coastal plain in northwestern Alabama (Fig. 1). The plateau is near its maximum width of 200 + miles (320 km) where we cross it on the first day of the trip. It is much narrower to the south, in eastern Kentucky, where we will cross it toward the end of the trip.

The western boundary of the Appalachian Plateaus Province is marked by a conspicuous escarpment that generally follows the contact between Mississippian and Devonian bedrock. The eastern boundary between the Plateau and the Ridge and Valley Province generally is marked by a maturely-dissected escarpment.

The Appalachian Plateaus Province has been divided into several sections. The unglaciated, maturely-dissected middle portion that we will cross in southern Ohio and West Virginia is called the Allegheny Plateau, whereas the southern counterpart of the Allegheny Plateau in Kentucky and Tennessee is called the Cumberland Plateau. The area along the eastern margins of the Allegheny and Cumberland plateaus generally exhibits considerable relief, and dissection is so advanced that the topography has lost its plateau characteristics. This area frequently is referred to as the Allegheny/Cumberland Mountains section.

Rocks of the Appalachian Plateau were deposited in the Appalachian Basin foreland area, on the east edge of the continental platform. The rocks, although generally flat-lying, reflect the synclinal structure of the plateau, with strata on the northwest dipping gently ($1-3^{o}$) toward the east-southeast, and strata in the eastern plateau dipping gently toward the west-northwest.

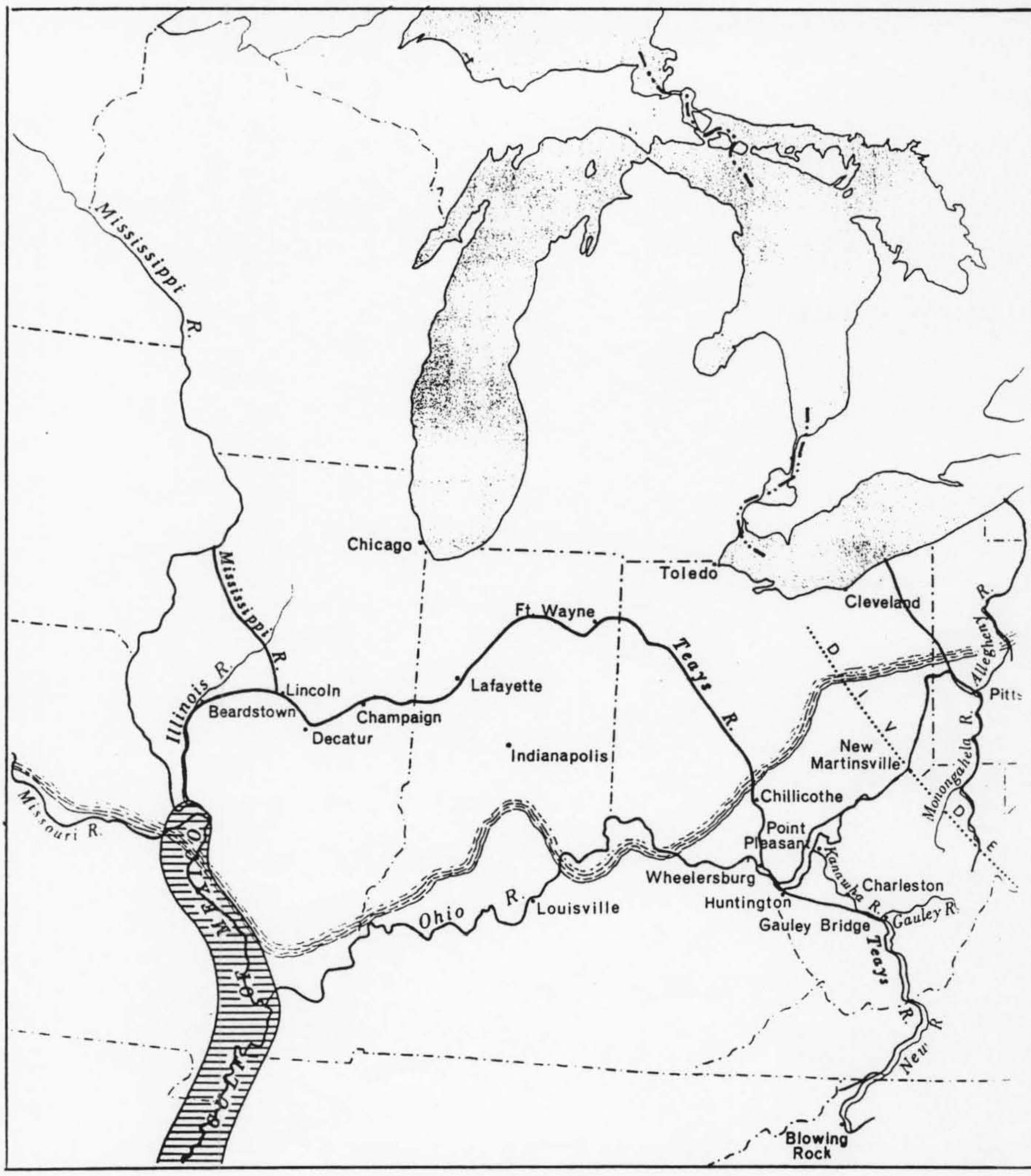


Figure 3. Teays drainage (from Janssen, R.E., 1952, The history of a river: Scientific American, v. 186, no. 6, p. 74-80.

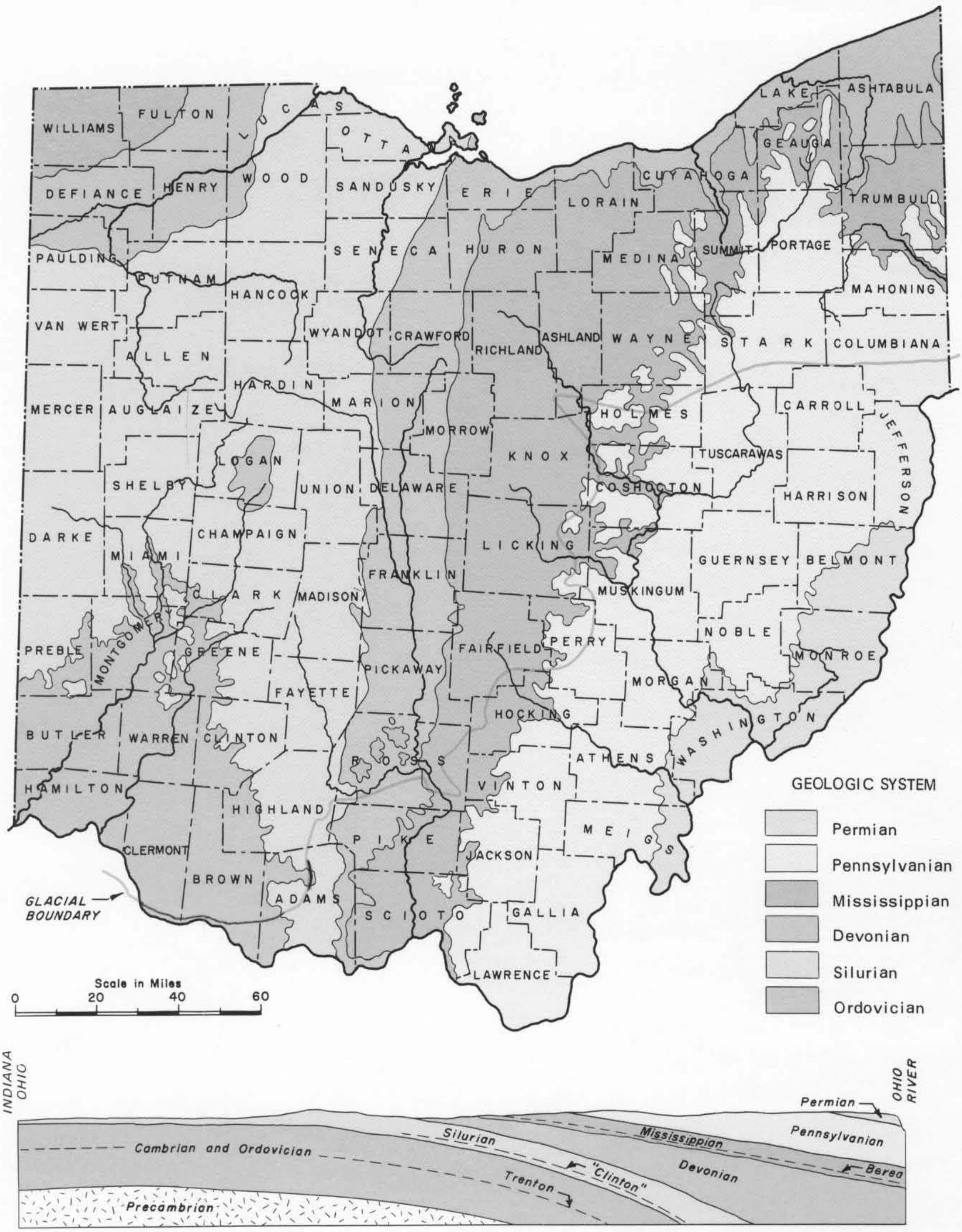


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Figure 4. GEOLOGIC MAP AND CROSS SECTION OF OHIO

FIGURE 5. Generalized Rock Column for Ohio (Modified from Ohio Geological Survey, Janssens' 1972 revised edition).

TIME-STRATIGRAPHIC UNITS		ROCK UNITS		
SYSTEM	SERIES	GROUP	FORMATION *Units found in the subsurface only are indicated in italics*	PRINCIPAL MEMBERS OR BEDS
PERMIAN		Dunkard	Greene Fm	
PERMIAN ? / PENNSYLVANIAN		Dunkard	Washington Fm	Upper Marietta ss, Creston-Reds, Lower Marietta ss, Washington coal, Mannington ss, Waynesburg ss
PENNSYLVANIAN		Monongahela		Waynesburg coal, Uniontown coal, Benwood ls, U. Sewickley ss, Meigs Creek coal, Pittsburgh ss, Pittsburgh coal
PENNSYLVANIAN		Conemaugh		Connellsville ss, Morgantown ss, Gaysport ss, Ames ls, Saltsburg ss, Cow Run ss, Cambridge ls, Buffalo ss, Brush Creek ls, Mahoning ss
PENNSYLVANIAN		Allegheny		U. Freeport coal, U. Freeport ss, M. Kittanning coal, L. Kittanning coal, Clarion ss, Putnam Hill ls, Brookville coal
PENNSYLVANIAN		Pottsville		Homewood ss, U. Mercer ss, L. Mercer coal, L. Mercer ss, Massillon ss, Quakertown coal, Sciotoville ss, Sharon coal, Sharon ss, cong
MISSISSIPPIAN			Maxville Ls	
MISSISSIPPIAN			Logan Fm	Vinton Ss, Allensville Cong, Byer Ss, Berne Cong
MISSISSIPPIAN			Cuyahoga Fm	Black Hand Ss, Portsmouth Sh, Buena Vista Ss, Henley Sh
MISSISSIPPIAN			Sunbury Sh	
MISSISSIPPIAN			Berea Ss	
MISSISSIPPIAN			Bedford Sh	Cussewago Ss

SYSTEM	SERIES	GROUP	FORMATION (western / northwestern Ohio)	FORMATION (eastern Ohio)	PRINCIPAL MEMBERS OR BEDS
DEVONIAN	Chautauquan ?		Ohio Sh		Cleveland Sh, Chagrin Sh, Huron Sh
DEVONIAN	Senecan	Traverse	NORTHWESTERN OHIO: Tenmile Creek Dol; Silica Fm	EASTERN OHIO: Olentangy Sh	
DEVONIAN	Erian		Dundee Fm	Delaware Ls	
DEVONIAN	Ulsterian	Detroit R.	dolomite and Sylvania Ss	Columbus Ls	
DEVONIAN	Ulsterian		rocks absent because of erosion or nondeposition	*Bois Blanc Fm*; *Oriskany Ss*; *Helderberg Ls*	
SILURIAN	Cayugan		Bass Islands Dol (outcrops in Ottawa County only)		
SILURIAN	Cayugan	Salina	WESTERN OHIO: dolomite; Tymochtee Fm; Greenfield Fm	EASTERN OHIO: G unit, F unit (outcrops in Ottawa County only); *D and E units*; *C unit*; *B unit*; *A unit*	
SILURIAN	Niagaran	Lockport	NORTH-CENTRAL OHIO: Guelph Dol; *Goat Island Dol*; *Gasport Dol*	EASTERN OHIO: *Lockport Fm undifferentiated*	
SILURIAN	Niagaran		Rochester Sh		
SILURIAN	Niagaran		Dayton Fm		
SILURIAN	Niagaran / Alexandrian		unnamed shale		
SILURIAN	Alexandrian		unnamed dolomite		
SILURIAN	Alexandrian	Cataract	WESTERN OHIO: Cabot Head Fm.; Brassfield Fm.	EASTERN OHIO: *sandstone and shale*	
ORDOVICIAN	Cincinnatian		SOUTHWESTERN OHIO: limestone and shale; Fairview Fm; Kope Fm	NORTHERN AND EASTERN OHIO: Queenston Sh; *shale and limestone*	
ORDOVICIAN	Cincinnatian		Trenton Ls		
ORDOVICIAN	Champlainian		*Black River Ls*		
ORDOVICIAN	Champlainian		*Glenwood Fm (Wells Creek Fm)*		
ORDOVICIAN ?	Canadian		*Knox Dol*		
CAMBRIAN	St. Croixan		*Kerbel Fm*		
CAMBRIAN	St. Croixan		WESTERN OHIO: *Eau Claire Fm*	EASTERN OHIO: *Conasauga Fm*; *Rome Fm*	
CAMBRIAN	St. Croixan		*Mt. Simon Ss*		
PRE-CAMBRIAN			*basement complex*		

Surface rocks of the Plateau generally are younger than those of other Appalachian provinces. They mainly are of Mississippian and Pennsylvanian ages, with a small area in Pennsylvania, Ohio and West Virginia underlain by Permian-age Dunkard Series strata (figs. 4 and 5). Rocks outcropping in the area dominantly are clastic --- conglomerates, sandstones, siltstones and shales plus interbedded coals.

Coal seams and related strata of Pennsylvanian age frequently exhibit more-or-less consistent repetitive stratification. Stratification of this type has been recognized in Carboniferous rocks in many parts of the world, with each repeating sequence being referred to as a cyclothem. A typical cyclothem is shown in Figure 6.

References (Appalachian Plateau)

Dunbar, C.O., and Rodgers, J., 1957, Principles of stratigraphy: Wiley, New York, 556 p.

King, P.B., 1977, The Evolution of North America, Revised edition: Princeton Univ. Press, Princeton, N.J., 197 p.

McKenzie, G.D., and Utgard, R.O., 1985, Field quide to the geology of parts of the Appalachian Highlands and adjacent Interior Plains: Zip Services, Columbus, OH, 111 p.

Thornbury, W.D., 1965, Regional Geomorphology of the United States: Wiley, New York, 609 p.

JOHN E. AMOS PLANT

The Appalachian Plateaus Province is one of the major coal producing areas in the world. The principal use for the coal is in the production of electricity. The John E. Amos plant is a coal-burning, steam-electric generating plant located on the banks of the Kanawha River, about 15 miles northwest of Charleston, West Virginia, in the midst of the Appalachian coal fields. Most of the coal burned here is low sulfur (0.8% average) West Virginia bituminous.

The Amos plant, one of the largest in the United States, is part of the American Electric Power System, which serves customers in parts of seven states. The plant has a total generating capacity of 2,900,000 kilowatts, and consists of three units, two with generating capacities of 800,000 kilowatts each, and a third with a generating capacity of 1,300,000 kilowatts.

Water used in the steam generating process and for cooling is taken from the Kanawha River at a rate of about 26,000 gallons per minute. This water replaces water lost through evaporation during cooling. No heated water is returned to the river, but instead it passes through one of three giant hyperbolic-shaped cooling towers, where it is cooled and recirculated to the plant.

Each of the generating units at the Amos plant is equipped with electrostatic precipitators whose job it is to remove ash that is produced during burning of coal before it can escape to the atmosphere. These precipitators are designed to be 99.7% efficient, and they remove more than 100 tons of flyash per hour from the plant emissions.

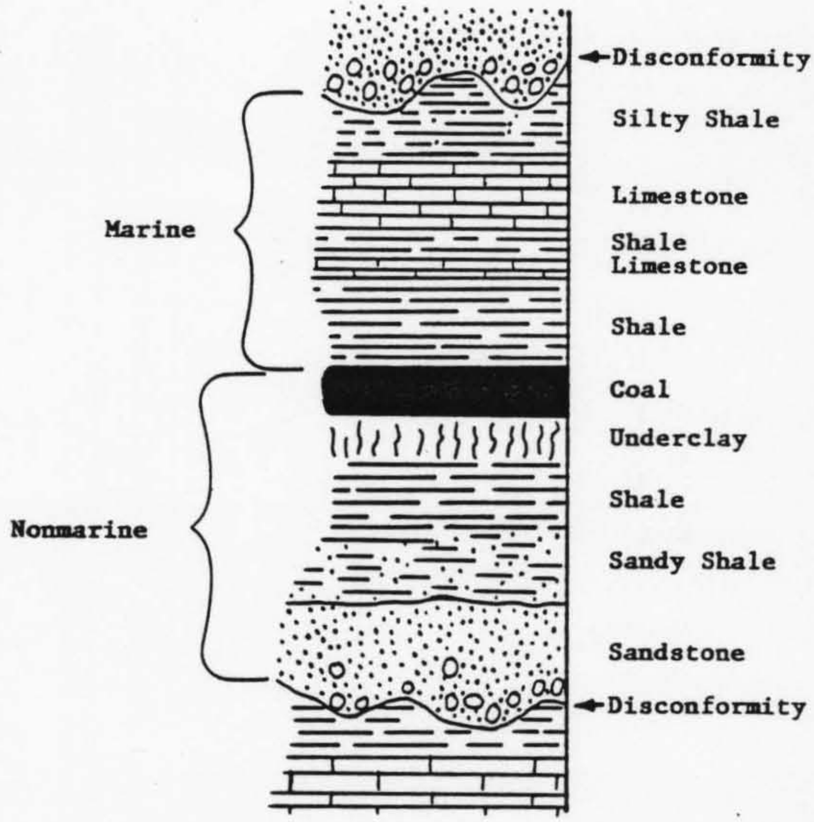


Figure 6. A cyclothem, typical of Pennsylvanian deposits in the eastern interior of North America. Rocks from the lower disconformity to the top of the coal bed are nonmarine, whereas those from the top of the coal to the higher disconformity contain marine fossils. The underclay just below the coal is thought to be the soil on which the coal forest grew. Not all units are present in every cyclothem (modified from Bates, R.L., Sweet, W.C., and Utgard, R.O., 1973, Geology an introduction, 2nd ed.: D.C. Heath, Lexington, Mass, 541 p.)

- Day 2 -

Princeton, West Virginia

to

North Wilkesboro, North Carolina

± 150 miles (243 km)

We will leave the Appalachian (Cumberland) Plateau in early morning today and cross the Ridge and Valley and Blue Ridge provinces, before crossing the Brevard Zone into the Inner Piedmont by evening. We will examine the structure and rocks of the Ridge and Valley, and rocks in the Blue Ridge. One of our stops will be to examine a large body of "granite" that has intruded into Blue Ridge rocks.

Major Stops

1. Overturned beds on southeast limb of Hurricane Ridge Syncline at Oakvale, West Virginia

2. Glen Lyn, Virginia section

3. Rich Creek and Narrows area

4. Cloyd's Mountain semi-anthracite coal

5. Draper Mountain overlook

6. Sylvatus, Virginia quarry

7. Blue Ridge escarpment

8. Mount Airy, North Carolina granite quarry

RIDGE AND VALLEY PROVINCE

The Ridge and Valley Province, sometimes called the "Folded Appalachians" or "Newer Appalachians" (Fig. 1), extends for a distance of 1200 miles (1932 km) from Alabama to the St. Lawrence Lowland. The width of the belt varies from 15 to 75 miles (24 to 121 km). Folded and faulted rocks of the Ridge and Valley consist of 30,000 to 40,000 feet (9144 to 12,192 m) of generally unmetamorposed sedimentary rocks of predominantly early Paleozoic age (Fig. 7).

The Ridge and Valley Province is characterized by marked parallelism of northeast-southwest-trending ridges and valleys; topographic forms developed on alternating resistant and non-resistant strata (Fig. 8); trellised drainage patterns; and many water gaps through hard rock ridges.

Throughout most of the length of the Ridge and Valley Province the eastern portion is characterized by a more-or-less continuous broad lowland area called "the Great Valley". The western portion of the province generally is dominated by ridges, with as many as 10 linear ridges in some areas.

The structural fabric varies considerably within the Ridge and Valley Province. To the north in Pennsylvania, folds with minor faulting are characteristic, whereas further south in southwestern Virginia and Tennessee the folds become compressed, overturned, and broken by thrust faulting toward the northwest (Fig. 9).

For many years, geologists have argued over whether or not deformation in the Ridge and Valley involved the crystalline basement rocks (thick-skinned tectonics), or if the deformation was confined to the sedimentary strata overlying the basement (thin-skinned tectonics). In the late 1970's, a COCORP (Consortium for Continental Reflection Profiling) seismic-reflection survey showed that the deformation primarily is thin-skinned. The folded and faulted sedimentary strata appear to have ridden westward over large, horizontal detachment zones on top of the crystalline basement.

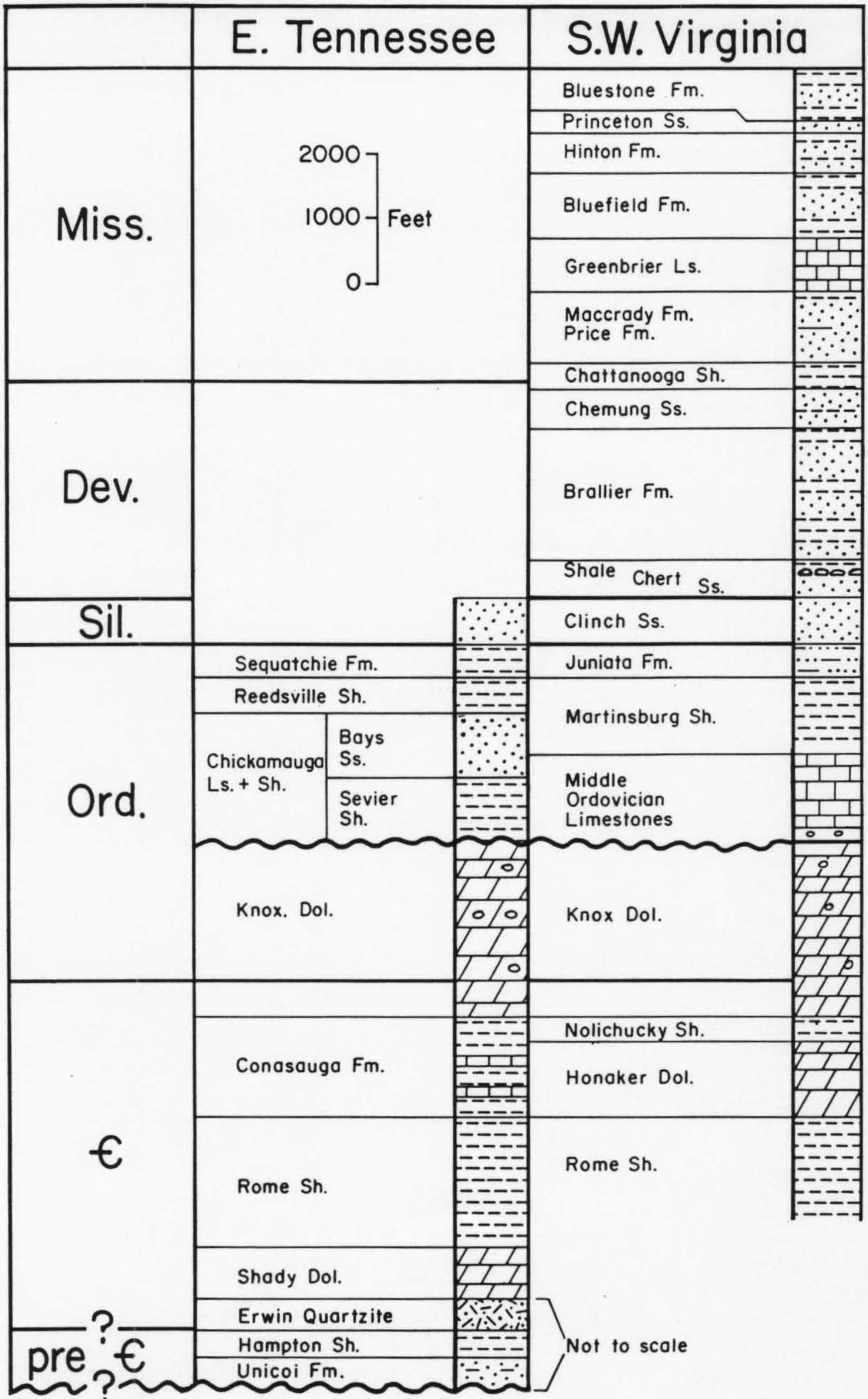
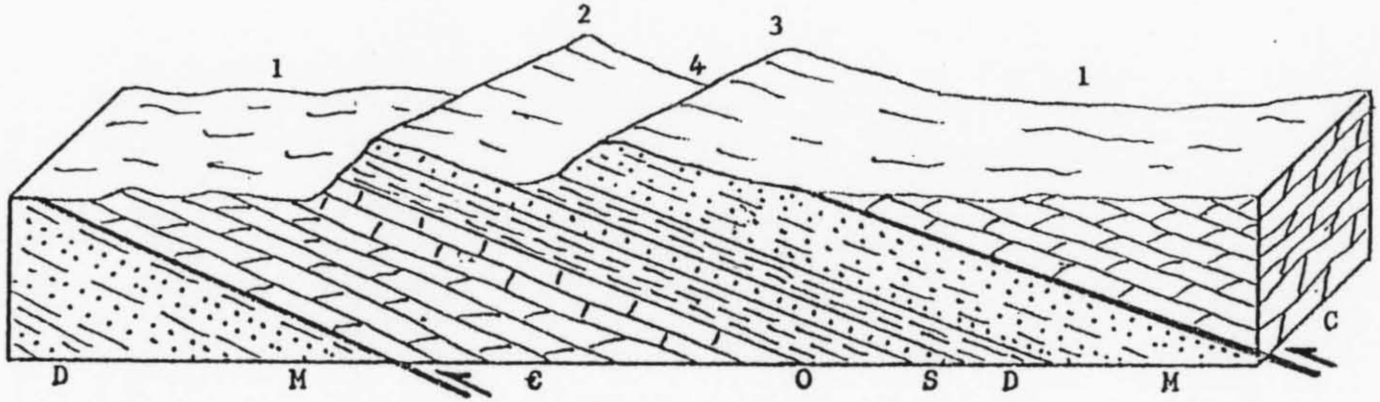


FIGURE 7. Geologic columns for Eastern Tennessee and Southwestern Virginia.



1. Cambro-Ordovician limestones and dolomites make broad fertile valleys.

2. The Silurian Clinch sandstone makes a prominent ridge, with a steep escarpment on one side and a long dip slope on the other.

3. Mississippian sandstones also make a pronounced ridge, with similar slopes.

4. Devonian shales make a "poor valley" between the ridges.

Figure 8. Relation between lithology and topography in the Valley and Ridge.

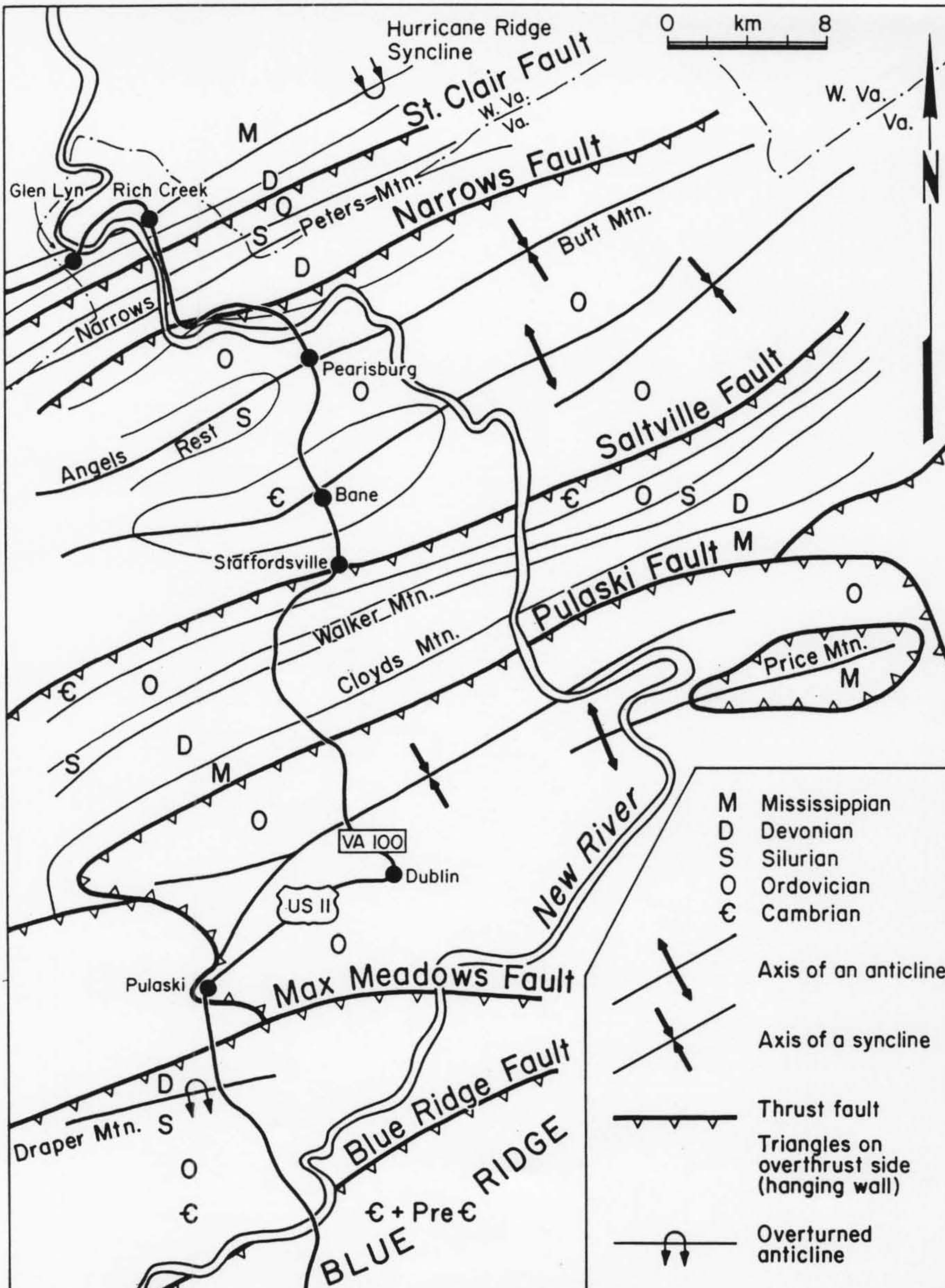


Figure 9. Geologic sketch map of Valley and Ridge Province from Glen Lyn to Sylvatus.

BLUE RIDGE PROVINCE

East and southeast of the Ridge and Valley Province, the Blue Ridge Province extends from southern Pennsylvania to northern Georgia, a distance of 550 miles (885 km). To the north in Pennsylvania the province is a single narrow ridge, but it broadens to the south so that in the area of Asheville, North Carolina it attains a width of about 80 miles (130 km). The broad area to the south does not display marked lineation of topography but is made up of several mountain groups (e.g. the Unakas and Great Smokies).

In the southern part of the Blue Ridge, the eastern margin is marked by a prominent escarpment called the Blue Ridge Front, which deliniates the physiographic boundary between the Blue Ridge and Piedmont provinces. The geologic boundary between the provinces, based mainly on petrologic and structural differences, generally is placed at the "Brevard Zone" (see later section).

The boundary between the Blue Ridge and the Ridge and Valley provinces to the west generally is marked by a thrust fault, which has been called the "Blue Ridge Thrust" or the "Great Smoky Thrust". Along the thrust, metamorphosed rocks of the Blue Ridge have been thrust northwestward over carbonate rocks of the Ridge and Valley Province.

Rocks of the western Blue Ridge Province consist of Lower Cambrian clastics of the Chilhowee Series and Upper Precambrian metagraywackes and slates of the Ocoee Series. Further east, Blue Ridge rocks are made up of Precambrian basement complex gneissic and plutonic rocks.

Up until the time of the COCORP studies of the Southern Appalachians, most geologists thought that the rocks of the Blue Ridge were rooted in place and were a part of the main body of continental basement complex rocks. However, COCORP seismic-reflection studies suggest that horizontal, layered sedimentary rocks underlie the Blue Ridge and that crystalline rocks have been thrust over the sedimentary strata along a major subhorizontal fault. Additional support for this conclusion comes from the fact that unmetamorphosed sedimentary rocks underlie older crystalline rocks within several structural "windows" through the Blue Ridge thrust plate.

References (Ridge and Valley and Blue Ridge Provinces)

Cook, F.A., Brown, L.D., and Oliver, J.E., 1980, The Southern Appalachians and the growth of continents: Scientific American, V. 243, no. 4, pp 156-168.

Thornbury, W.D., 1965, Regional Geomorphology of the United States: Wiley, New York, 609 p.

MT. AIRY GRANITE QUARRY

The North Carolina Granite Corporation quarry at Mt. Airy is within an oval-shaped stock or batholith that is about 8 miles long in its northeast-southwest dimension and about 4 miles wide. The granite quarried here is a light gray medium-grained uniform rock that is known in the trade as "white granite". Actually, it is not a true granite, but a granodiorite or more specifically a leucogranodiorite. It contains about 55% plagioclase (oligoclase), 20% microcline, 20% quartz, and 5% biotite and accessory minerals. Accessory minerals include muscovite, epidote, apatite, zircon, monazite, sphene, and magnetite.

The country rock consists chiefly of muscovite and/or biotite-bearing gneisses and schists plus amphibole-rich foliates (Dietrich, 1961). These rocks are poorly exposed in the quarry, but we get some idea of the type of country rock from xenoliths in the granite. The xenoliths are not abundant, but a few up to several meters in long dimension have been encountered. Both the granite and country rock are deeply weathered and outcrops of unweathered rock are scarce, except at the large dome-like outcrop in which the quarry is located.

The granite at Mt. Airy likely was emplaced as magma (temperature 650^{o} - 710^{o} C) at a depth of 2.3 to 12 miles below the earth's surface. Radiometric dating gives an age of 356 $\pm$ 12 m.y. for the granite (Long et al., 1959), which corresponds to the time of the Acadian Orogeny. The age of the basement rocks of the Blue Ridge and Inner Piedmont provinces generally is thought to be Precambrian, with large portions of the area being metamorphosed initially at about 900 to 1100 m.y. ago, the same time as major events in the Grenville Province.

The quarry at Mt. Airy, which began producing dimension stone in 1889, is one of the world's largest open-pit quarry operations. Products now include dimension stone for memorials and mausoleums, architectural stone, curbing, paving blocks, and crushed stone for aggregate and poultry grit. There is practically no waste in the operation because the waste rock is crushed and marketed for various uses. About 3000 carloads of stone are shipped per year, half of this by truck. There are about 250 employees in the quarry, office, and cutting operations. Machinery in the cutting sheds includes gang, wire, and rotary saws, and grinding, polishing, and sandblasting equipment.

Extraction of blocks of granite in the quarry takes advantage of the natural tendency of the massive rock to develop sheeting parallel to the surface. Layers of granite or "lifts" are separated from the main mass of rock by inducing horizontal sheeting planes four to eight feet below the surface. In this process, a two and one-half inch hole is drilled in the center of the sheet to be lifted; small amounts of black powder then are successively detonated at the bottom until horizontal cracks develop. Additional larger charges may be needed to continue propagation of the split, although natural diurnal heating and cooling in the summer may result in continued propagation. Completion of a lift sometimes requires a month or more, with daily charges being set, and additional holes may have to be drilled near the edge of the split.

Blocks of granite are quarried from a lift by drilling holes four inches deep and four inches apart along a line. Wedges are inserted in the holes and then hit with a sledge hammer until the rock fractures. In this way blocks of the desired size are broken from a sheet. The granite then is cut and finished in the cutting sheds.

References (Mt. Airy Granite Quarry)

Dietrich, R.V., 1961, Petrology of the Mount Airy "Granite": Bull. of the V.P.I., Engr. Exp. Station Series No. 144, v. 54, no. 6, 63 p.

Long, L.E., Kulp, J.L., and Eckelmann, F.D., 1959, Chronology of major metamorphic events in the southeastern United States: Amer. Jour. Sci., v. 257, p. 585-603.

North Carolina Granite Corp. information bulletins.

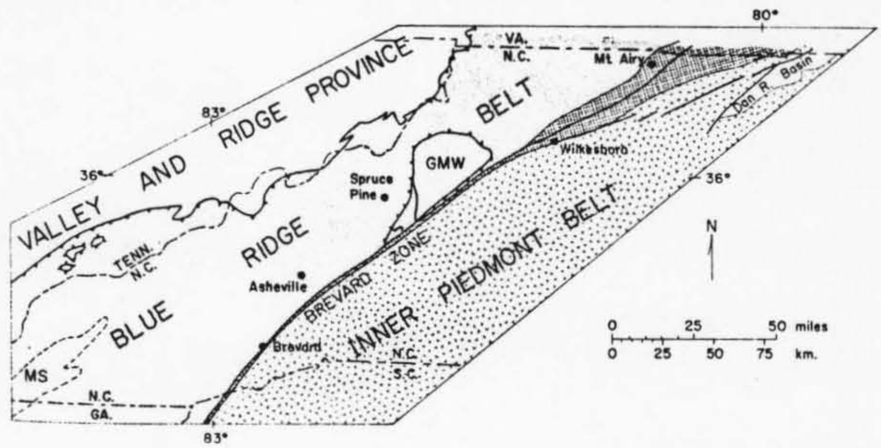


Figure 10. Major geologic belts in western North Carolina and adjacent parts of Tennessee. GMW-Grandfather Mountain window, MS-Murphy synclinorium (from Butler, 1973).

BREVARD ZONE

The Brevard zone is a narrow belt of steeply dipping, low grade metamorphic rocks known to extend for at least 375 miles (600 km) from the coastal plain overlap in Alabama across the Virginia-North Carolina state line northeast of Mt. Airy, North Carolina (Fig.10). The belt has a maximum width of only a few miles, but for at least the northern two-thirds of its length it separates the Blue Ridge and Inner Piedmont geologic provinces. Locally, the location of the geologic boundary coincides with the physiographic boundary between the two provinces, although we descended the physiographic boundary several miles before intersecting the Brevard zone on the way to Wilkesboro, North Carolina.

Rocks within the Brevard zone perhaps are equivalent to Cambrian-age rocks elsewhere; they are predominantly dark-gray to black graphitic schist, phyllite, slate and fine-grained biotite gneiss, locally containing layers and lenses of quartzite and marble. Mylonite and ultramylonite also are present within the zone.

Several hypotheses have been forwarded to explain the origin of the Brevard zone, and in fact, its history may record deformation during all of the major Paleozoic Appalachian orogenic events. Among the suggestions for the origin of the Brevard zone are that it originated 1) as a tightly infolded syncline of Cambrian rocks that originally were deposited unconformably on Precambrian rocks; 2) as a major thrust fault; 3) as a normal fault; 4) as a major strike-slip fault with right lateral displacement (or, with left lateral displacement); 5) as a combined strike-slip and thrust fault; 6) as an Alpine-type root zone to a knappe structure; 7) as a subduction zone and 8) as the suture zone between North America and Africa, along which the proto-Atlantic ocean finally closed. Whatever the case, most workers agree that major movement on the zone ceased prior to the Mesozoic.

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- Day 3 -

North Wilkesboro, North Carolina

to

Maggie Valley, North Carolina

$\pm$ 195 miles (314 km)

Upon leaving N. Wilkesboro, we will spend the day within the Blue Ridge province. We will cross the Brevard zone; travel for some distance along the Blue Ridge Parkway; traverse the Grandfather Mountain structural window; and visit the Spruce Pine mining district. While in the Spruce Pine area, we will visit an alaskite quarry, a clay pit, and a dunite mine before traveling on to Maggie Valley, N.C. for the night.

Major Stops

1. Brevard zone
2. Scenery and geology, Blue Ridge Parkway
3. Grandfather Mountain window (figs. 11 and 12)
4. Alaskite quarry, Spruce Pine area (Fig. 14)
5. Harris Co. clay pit, Spruce Pine area (Fig. 15)
6. Dunite mine north of Burnsville, NC (Fig. 16)

BLUE RIDGE PARKWAY

Established June 30, 1936, the Blue Ridge Parkway is administered by the National Park Service, U.S. Department of the Interior. The Parkway, a unit of the National Park System, extends 469 miles (755 km) through the southern Appalachians, through vistas of quiet natural beauty and rural landscapes lightly shaped by the activities of man. Designed especially for motor recreation, the Parkway provides quiet, leisurely travel, free from commercial development and the congestion of high-speed highways. It follows mountain crests to link Shenandoah National Park in northern Virginia and Great Smoky Mountains National Park in North Carolina and Tennessee.

Rhododendron, azalea, white pine and other native plants border the roadsides. Overlooks, campgrounds, picnic areas, trails and wayside exhibits all contribute to the vista. Views are enlivened by highland farms with split-rail fences, weathered cabins and gray barns that compose the "hill culture" of the southern Appalachians.

While on the Parkway, we will be driving mainly within Precambrian/Lower Paleozoic (?) laminated micaceous gneiss and schist. The rock typically is finely laminated and is composed of fine-grained quartzo-feldspathic layers a few millimeters thick separated by thin micaceous partings. Interlayers of amphibolite, garnet amphibolite, and hornblende gneiss, plus biotite-muscovite gneiss and mica schist may be seen.

GRANDFATHER MOUNTAIN WINDOW

As we traverse the Blue Ridge Parkway on our way southwestward toward Spruce Pine, North Carolina, we will pass through the Grandfather Mountain structural window in the Blue Ridge thrust sheet. The general geology of the window and the surrounding rocks, and a cross-section through the window are given in figures 11 and 12 (both adapted from Bryant and Reed, 1970).

The Grandfather Mountain window is 45 miles (72 km) long and as much as 20 miles (32 km) wide. Rocks exposed within the window include 1000 to 1100-million-year-old plutonic basement rocks, sedimentary and volcanic rocks of late Precambrian age, and Lower Cambrian Chilhowee Group sedimentary rocks.

The Blue Ridge thrust sheet surrounding the Grandfather Mountain window consists largely of schist, gneiss, and amphibolite, plus units of the Cranberry Gneiss, a complex of migmatite and granitic rocks that underlies the metasedimentary and metavolcanic rocks. All of the rocks surrounding the window are Precambrian age.

Layering and foliation in rocks of the Blue Ridge thrust sheet dip away from the Grandfather Mountain window on all sides. The rocks of the Blue Ridge sheet moved northwestward at least 35 miles (56 km) over the Grandfather Mountain window, after the close of metamorphism 350 m.y. ago (Late Devonian) and before Late Triassic(?) time. Right-lateral strike-slip movement along the Brevard Zone was concurrent with, but may have lasted somewhat longer than, thrusting. The lateral displacement was greater than 135 miles (217 km).

Reference (Grandfather Mountain Window)

Bryant, B., and Reed, J.C., Jr., 1970, Geology of the Grandfather Mountain window and vicinity, North Carolina and Tennessee: U.S. Geol. Surv. Prof. Paper 615, 190 p.

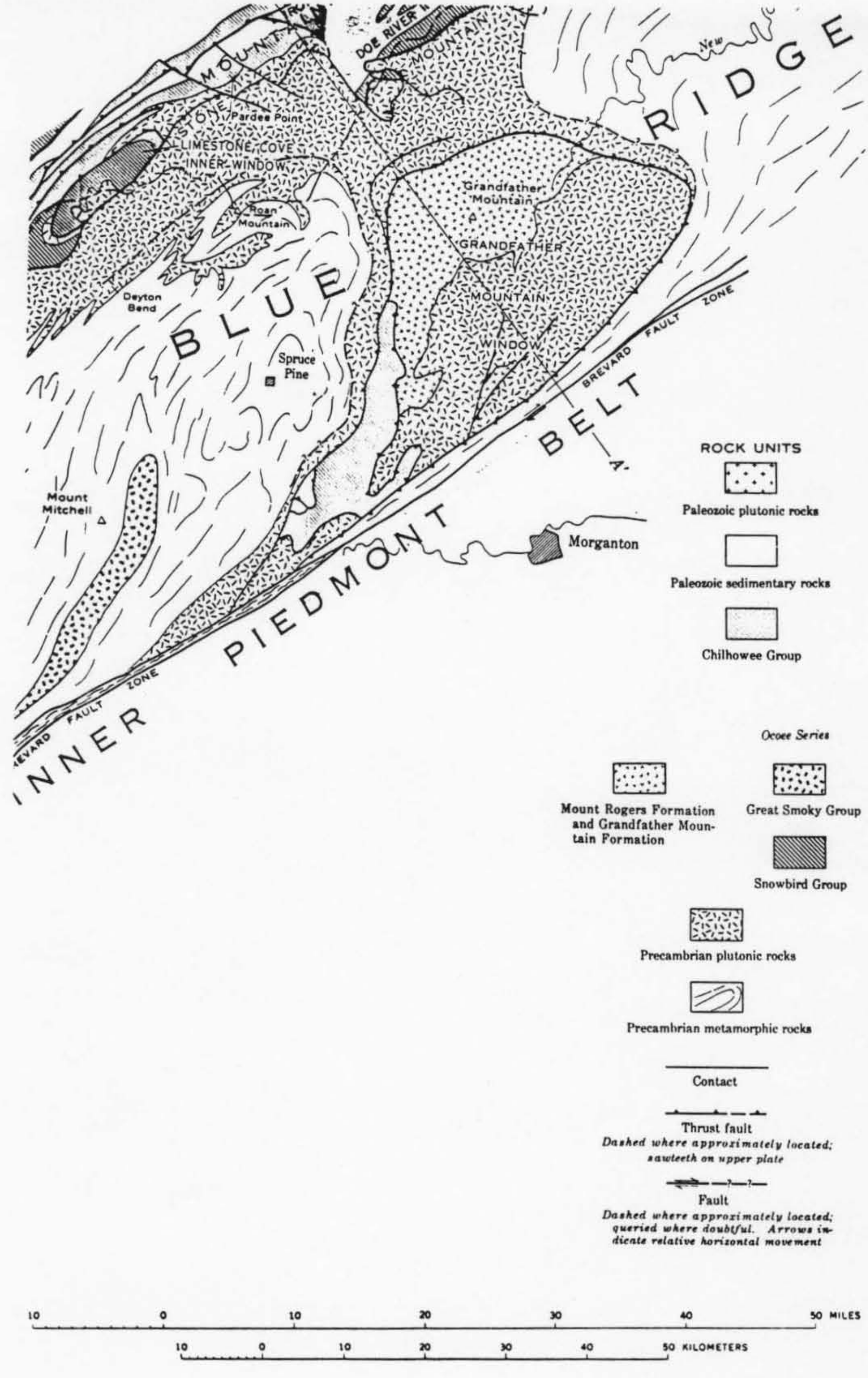

Figure 11. Geologic map of Grandfather Mountain Window and vicinity (from Bryant and Reed, 1970).

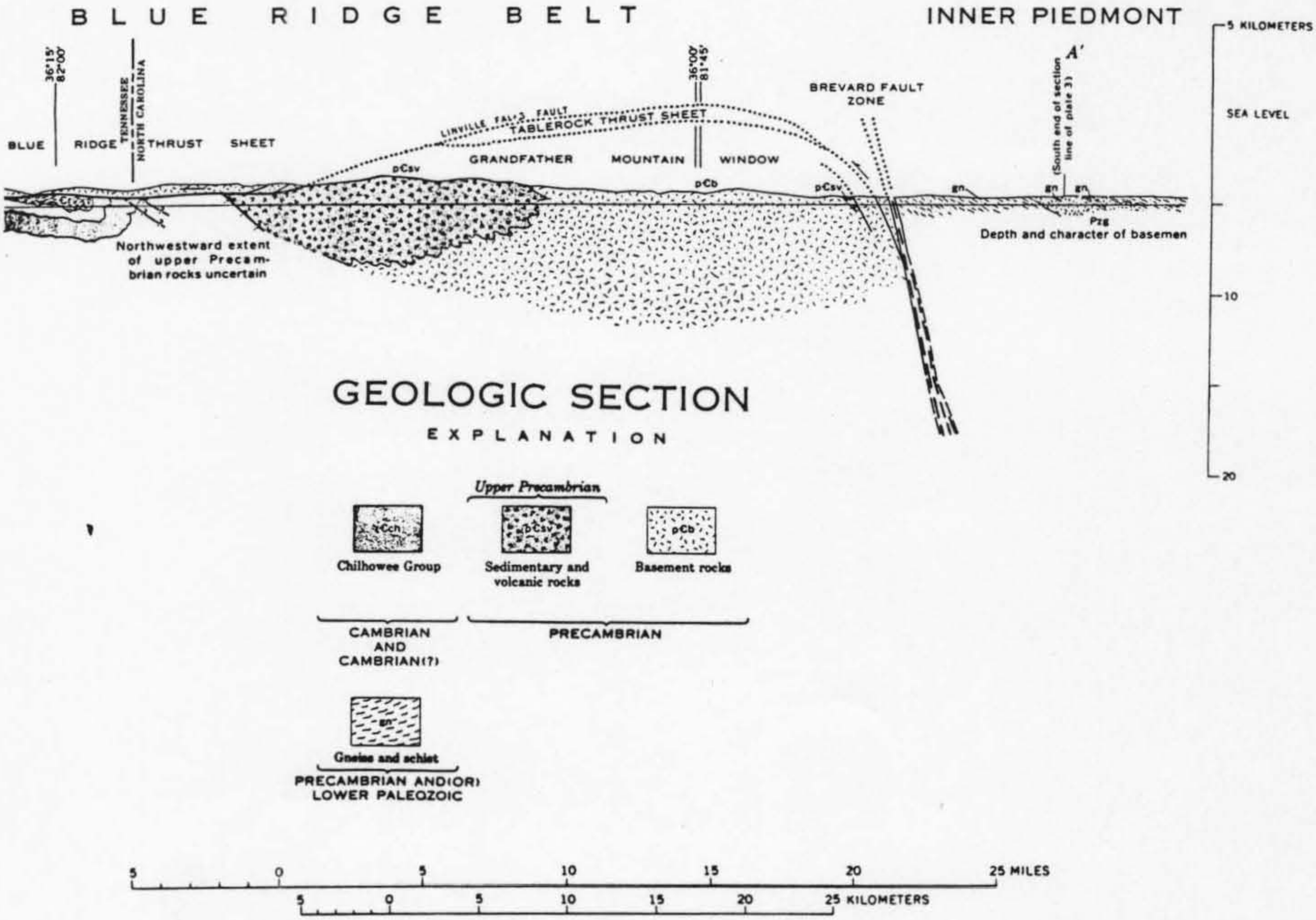

Figure 12. Geologic section of Grandfather Mountain Window and Brevard Zone, along line A-A' ib Figure 11 (From Bryant and Reed, 1970).

SPRUCE PINE DISTRICT

Rocks of the Spruce Pine district lie within the Spruce Pine synclinorium (Fig. 13). The synclinorium is situated northwest of the Brevard zone, adjacent to the Grandfather Mountain window; it plunges to the southwest; and it is asymmetrical, with the steepest dips along the northwest margin. The structure is about 20 miles (32 km) wide and contains Precambrian micaceous and amphibolitic gneiss and schist that were intruded by dunite and alaskite with associated pegmatite in the Paleozoic, and by diabase dikes and sills of Triassic(?) age. The mineral production for which the Spruce Pine district is so well known is related to the Paleozoic intrusive bodies, or to products derived by weathering from the intrusive bodies.

In addition to the pegmatites for which it is famous, the Spruce Pine district contains large bodies of alaskite (40% oligoclase, 25% quartz, 20% microcline, and 15% muscovite, plus various accessory minerals). The pegmatites are similar to the alaskite in composition and they likely were related genetically to emplacement of the alaskite bodies (approx. 340 m.y.).

The principal mineral products of the Spruce Pine district are from the alaskite and associated pegmatites (Fig. 14). The chief products are feldspar, (scrap) mica, and kaolin. The feldspar is used in the production of glass, ceramic products and for enamel glaze. Sheet mica was produced in the past, but today it cannot compete with imported material as to price and quality. Scrap mica is produced as a product of feldspar milling, and it is used, e.g., in wall paper, paint and lubricants; as a filler in dusting powder for rubber products; and to prevent sticking, as backing for rolled asphalt roofing.

Kaolin deposits in the Spruce Pine area (Fig. 15) are composed predominantly of kaolinite plus some halloysite. They are residual deposits derived through chemical weathering of the alaskite and associated pegmatite bodies. Within the deposits, the clays are mixed with altered plagioclase, perthitic microcline and generally unaltered quartz and muscovite. The depth of kaolinization ranges from 40 to 100 feet (12 to 30 meters). All of the commerical deposits underlie older terrace levels of large streams and their major tributaries, at altitudes of 2550 to 2750 feet (777 to 838 meters) above sea level. The tops of the kaolin deposits are from 65 to 345 feet (20 to 105 meters) above the nearest large stream, and the bottoms of the deposits generally extend to stream level. The kaolin in the past was used in part in the production of china ware, but today production is taken up mainly as a filler in the manufacture of paper and ceramic products. Scrap mica is a byproduct of the processing of the kaolin.

Dunite deposits - Several small bodies of dunite are present within the Spruce Pine area. These bodies, like others in the Blue Ridge belt, are believed to have been emplaced about 450-480 million years ago (early Ordovician), prior to the beginning of the Taconic orogeny. We will examine the Day Book deposit (Fig. 16), which is being mined at the present time. The body is principally olivine, plus enstatite, chromite, and magnetite. Secondary minerals present within the body include serpentine, talc, chlorite, anthophyllite, tremolite, vermiculite, and magnesite.

The Day Book deposit is an Alpine-type ultramafic body that apparently formed as upwelled mantle material within a rift system (proto-Atlantic Ocean) along the ancient continental margin of North America. The material subsequently was squeezed and thrust into place during the Taconic orogeny. The lack of contact metamorphic effects or evidence of chilled borders to the body suggest that the dunite was emplaced "cold". Secondary mineralogy was produced by hydrous alteration during regional metamorphism and/or during intrusion of associated pegmatites (Fig. 16).

Today, the body is quarried for olivine that is used mainly as foundry molding sand.

References (Spruce Pine District)

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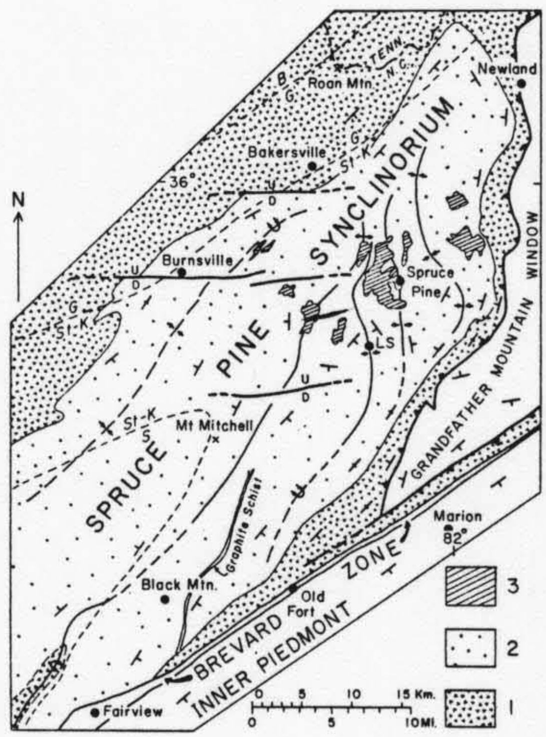

Figure 13. Generalized geologic map of part of the Spruce Pine synclinorium. Rock units: 1-Precambrian basement complex, including Cranberry Gneiss; 2-Late Precambrian Ashe Formation, mainly mica schist, mica gneiss, and amphibolite; 3-Middle Paleozoic Spruce Pine plutonic group, pegmatite and alaskite bodies. Isograd minerals: B-biotite, G-garnet, St-staurolite, K-kyanite, S-sillimanite. Isograds from Hadley and Nelson (1971). LS is location of Little Switzerland (from Butler, 1973).

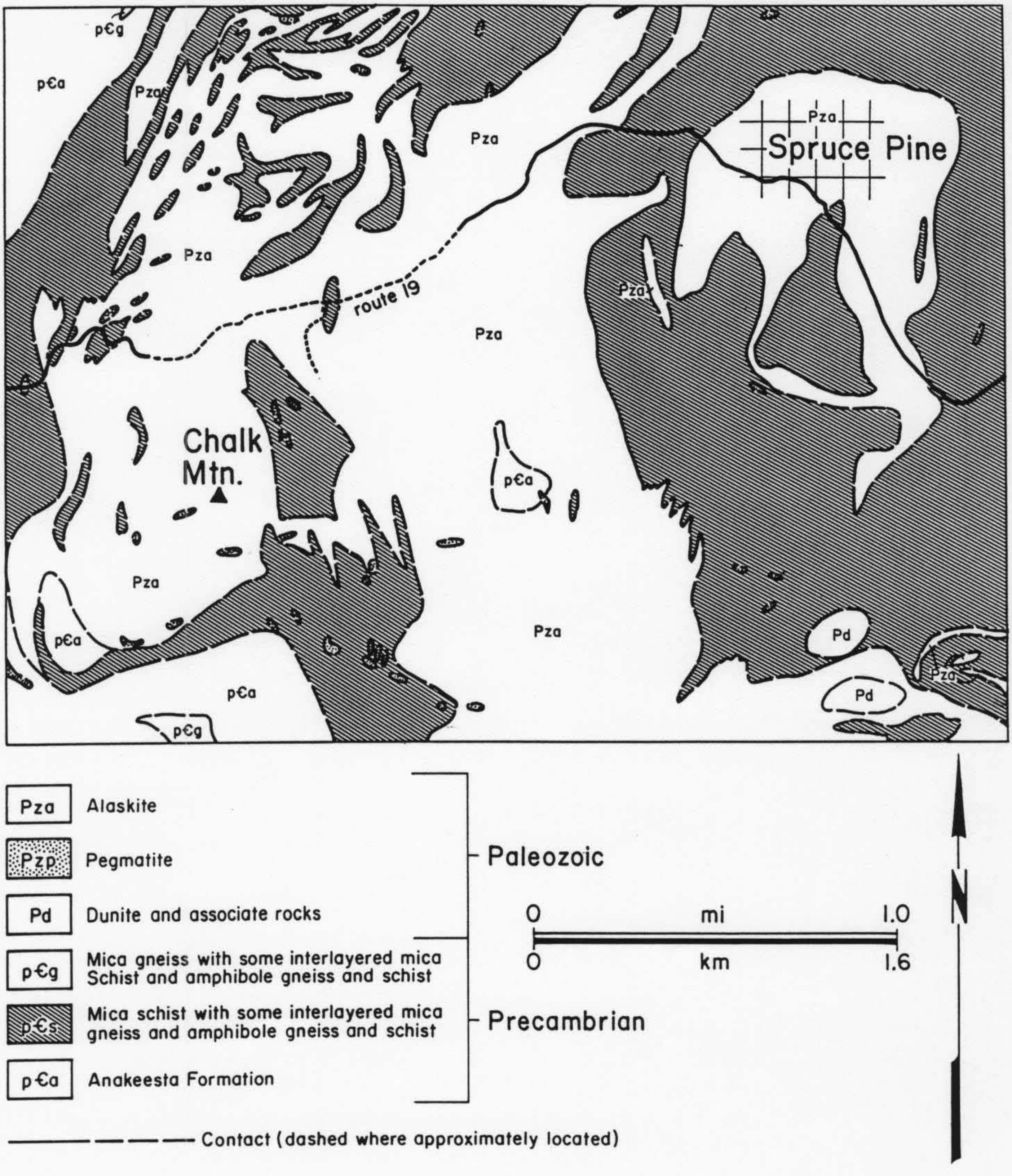

Figure 14. General geology of the region encompassing Spruce Pine and Chalk Mountain (adapted from Brobst, 1962).

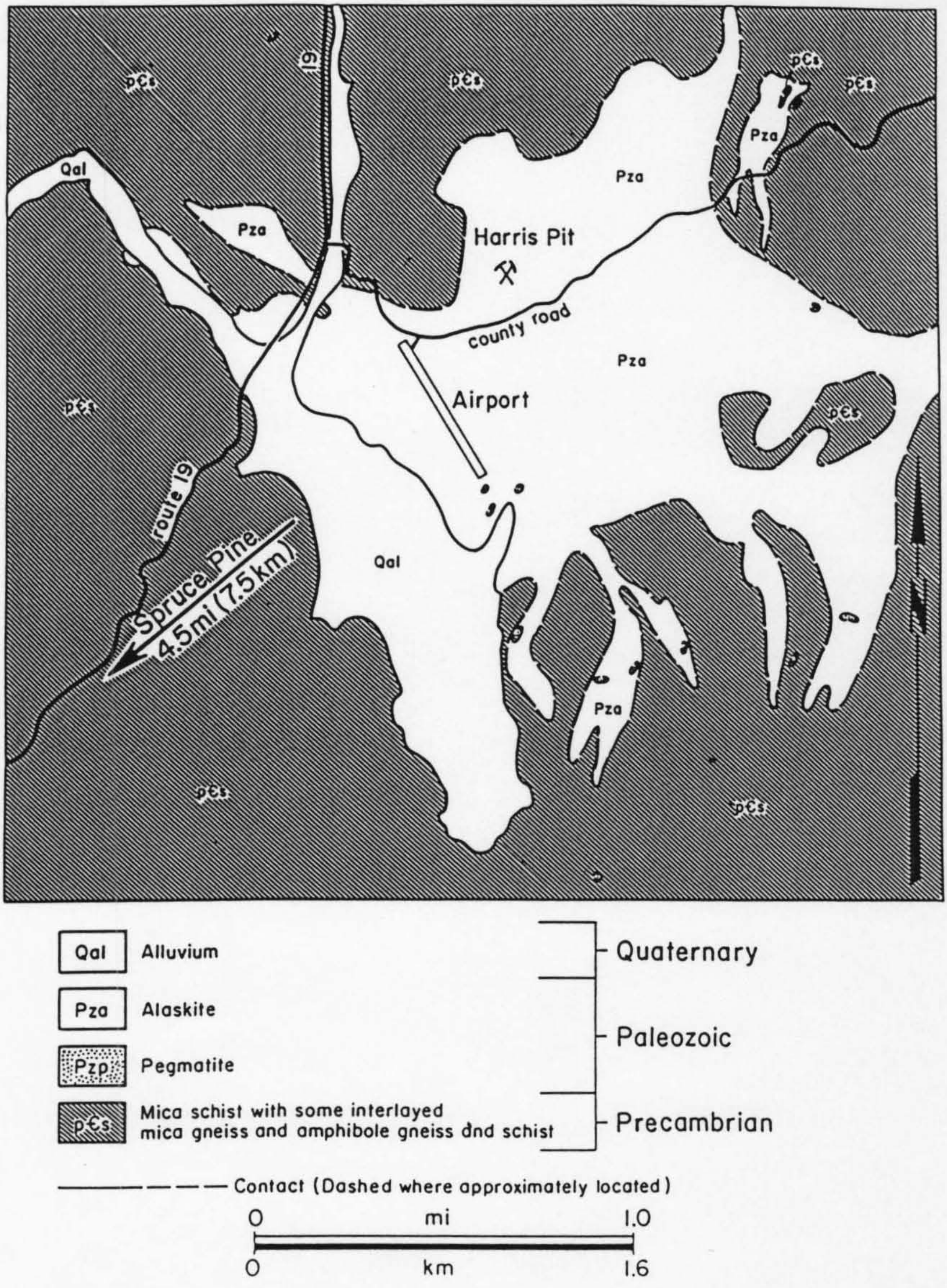

Figure 15. General geology of the region encompassing the Harris Clay Co. pit (adapted from Brobst, 1962).

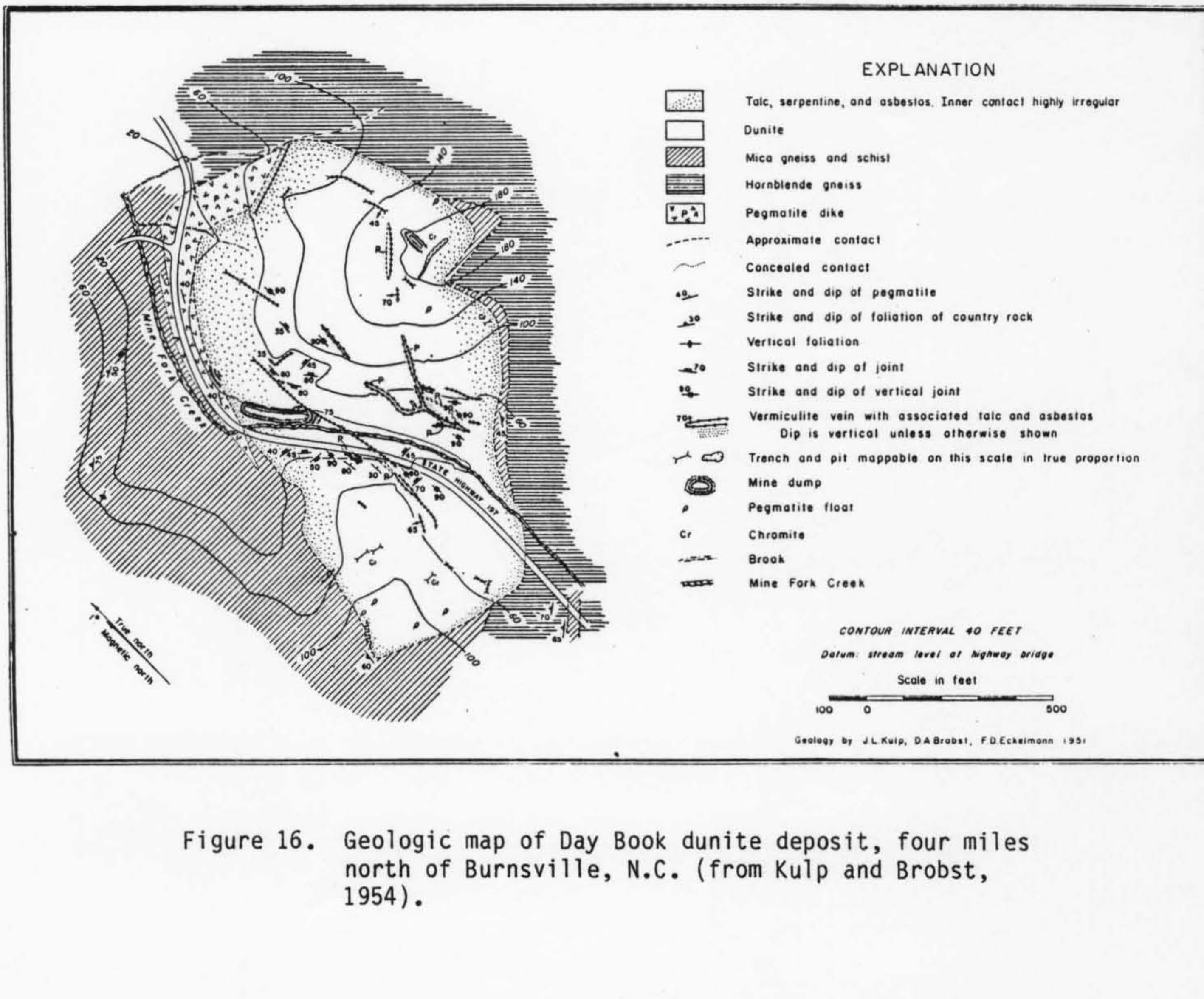

Figure 16. Geologic map of Day Book dunite deposit, four miles north of Burnsville, N.C. (from Kulp and Brobst, 1954).

- Day 4 -

Maggie Valley, North Carolina

to

Knoxville, Tennessee

$\pm$ 300 miles (483 km)

We will spend today largely within the Blue Ridge province, crossing back into the Ridge and Valley province sometime in the afternoon. Following a trip into the Great Smoky Mountains to examine the general geology, we will traverse the Murphy Marble belt, examine the geology and mineralization of the Ducktown mining district and travel down the Ocoee Gorge to the structural boundary between the Blue Ridge and Ridge and Valley provinces. Following a stop to examine this boundary, we will travel northeast within the Ridge and Valley province to Knoxville, Tennessee for the night.

Major Stops

1. Structure and rocks, Great Smoky Mountains (Fig. 17) (Newfound Gap, Clingmans Dome)
2. Rocks of the Murphy Marble Belt (figs. 18 and 19)
3. Structure and mineralization, Ducktown area (Fig. 20)
4. Structure and rocks of the Blue Ridge, Ocoee Gorge (Fig. 21)
5. Boundary between the Blue Ridge and Ridge and Valley (Fig. 21)

GREAT SMOKY MOUNTAINS

The Great Smoky Mountains of the Blue Ridge province include some of the highest summits in the eastern U.S., culminating within the park at Clingman's Dome, elevation 6642 ft. (2025 meters). The mountains are forested throughout, the summits being largely covered by spruce and fir, and the lower slopes by a variety of hardwoods. Much of the forested wilderness has been set aside for public enjoyment as the Great Smoky Mountains National Park.

Geology - Rocks of the Great Smoky Mountains (Fig. 17, Table II) link the Paleozoic sedimentary rocks of the Appalachian Valley to the northwest to the metamorphic and igneous rocks of the Blue Ridge to the southeast. Like the rocks of the Appalachian Valley, most of those in the Great Smoky Mountains are of sedimentary origin, and near the Valley these are largely unaffected by metamorphism. Unlike the rocks of the Valley, the rocks of the Smokies are a great mass of pebbly, sandy and muddy material that are lacking in fossil remains. By a gradual southeastward increase in shearing, recrystallization and metamorphism, these original sediments acquire more and more the aspect of the rocks of the Blue Ridge. These sedimentary rocks, the metamorphosed equivalents of which we will see, make up most of the Great Smoky Mountains and large parts of the adjacent foothills. They belong to the upper Precambrian Ocoee Series. The Ocoee rocks in turn have been subdivided into the Snowbird, Great Smoky and Walden Creek groups, the Snowbird Group being the oldest.

The Great Smoky Group, which forms the main mass of the Great Smoky Mountains, is a thick monotonous mass of clastic sedimentary rocks, pebble conglomerate, coarse-to-fine sandstone, and silty or argillaceous rocks that can be divided into three intertonguing formations - the relatively fine-grained Elkmont Sandstone below, the coarse-grained Thunderhead Sandstone in the middle, and the dark silty and argillaceous rocks of the Anakeesta Formation above. The general stratigraphic relationships of the southern part of the Great Smoky Mountains are given in Table II. We will see units of the Thunderhead Sandstone and the Anakeesta Formation.

The only igneous rock mapped in the region is (meta)diorite that forms narrow sills parallel to beds in the Thunderhead Sandstone near the mountain crest between Newfound Gap and Clingman's Dome (Fig. 17).

Notable structural deformation in the region of the Great Smoky Mountains probably began in the early Paleozoic, and is manifest in the Greenbrier and related faults, which moved Ocoee Series rocks northwestward several miles over other Ocoee Series rocks. At some later time in the Paleozoic, the Ocoee Series and its faulted structures were subjected to regional metamorphism. The rocks on the northwest were nearly unaffected, but those on the southeast attained medium-grade metamorphism.

Late in the Paleozoic, at least later than Mississippian, the whole mass of Ocoee Series rocks, as well as its cover of earliest Paleozoic rocks, was thrust many miles northwestward across the main body of Paleozoic rocks. Paleozoic rocks overridden by the thrust are now exposed in the cove areas within the Great Smoky Mountain National Park. During thrusting, the rocks above the Greenbrier fault were carried along with the rest, thus moving them a still greater distance from their original site of deposition.

A very late event in the deformation of the region, as young as or younger than the Great Smoky thrusting and most of the folding, was the breakup of Ocoee Series rocks by some combination of dip-slip and strike-slip fault movement.

Reference (Great Smoky Mountains)

King, P.B., Neuman, R.B. and Hadley, J.B., 1968, Geology of the Great Smoky Mountains National Park, Tennessee and North Carolina: U.S. Geol. Surv. Prof. Paper, 587, 23 p.

Table II

Stratigraphic Units of the Great Smoky Series of the Great Smoky Mountains National Park (adapted from King, et al., 1968).

		(South of and above Greenbrier fault)
Rocks of Murphy marble belt		Nantahala Slate and higher units (Early Paleozoic(?))
		Lithologic break, but probably conformable
Ocoee Series	Great Smoky Group	Unnamed sandstone
		Anakeesta Formation
		Thunderhead Sandstone
		Elkmont Sandstone
	Snowbird Group	Roaring Fork Sandstone
		Longarm Quartzite
		Wading Branch Formation
		Unconformity
Basement complex		

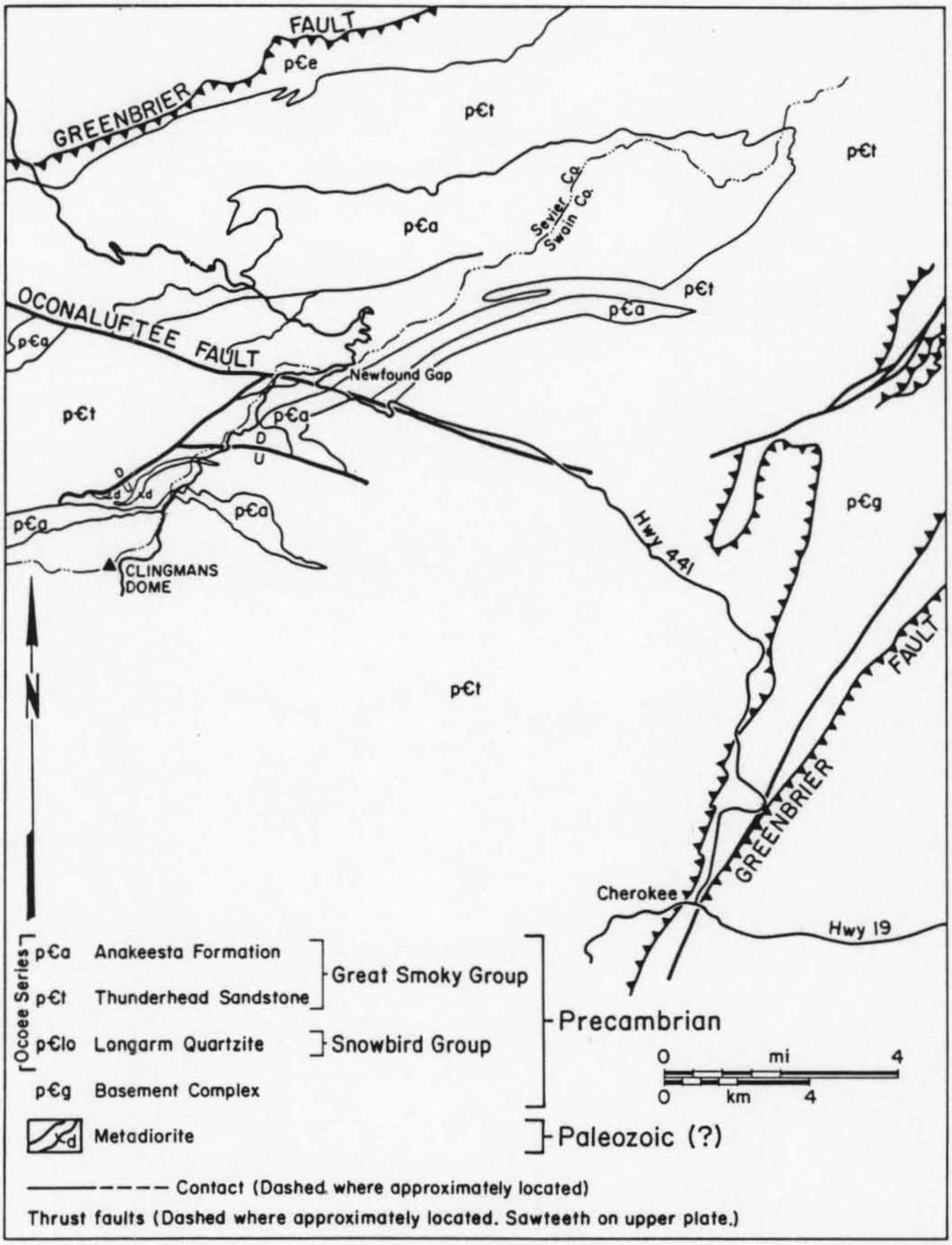

Figure 17. Geologic map of a portion of the Great Smoky Mountain National Park and vicinity, Tennessee and North Carolina (adapted from King, et al., 1968).

MURPHY MARBLE BELT

Rocks of the Murphy Marble belt overlie but are synclinally infolded with units of the Great Smoky Group (Fig. 18). The Murphy Marble actually is a dolomitic marble and it ranges to a maximum thickness of 197 feet (60 meters). Where it has been folded, the apparent thickness may be much greater (e.g., at Tate, Georgia, where the rock is extensively quarried). The marble unit is underlain by the Nantahala Formation, the Tusquitee Quartzite and the Brasstown Formation, which together range from 1476 to 3035 feet thick (450 to 925 meters); and the marble is overlain by about 985 feet (300 meters) of the Andrews Formation, Nottely Quartzite and Mineral Bluff Formation (Fig. 19). Together, these rocks comprise the Murphy Marble sequence, which probably reflects a transgressive-regressive environment in Lower Cambrian time, with the Murphy Marble being a barrier reef or carbonate bank. The rock is 95 percent or more carbonate, and thus must have been isolated sedimentologically from the more clastic units below and above.

At least two periods of regional metamorphism affected rocks of the southern Blue Ridge, including the Murphy Marble sequence. The first was from about 390 to 340 million years (Acadian Orogeny), and the second was at about 250 million years, corresponding to the Allegheny Orogeny.

We will cross the Murphy Marble belt between the Great Smoky Mountains and Ducktown, Tennessee. We will be making at least one road stop to examine schist units within the sequence, and we will pass several operations where the Murphy Marble either is being quarried or where it has been quarried in the past.

References (Murphy Marble Belt)

Hurst, V.J., 1973, Geology of the southern Blue Ridge belt: Amer. Jour. Sci., v. 273, p. 643-670.

Power, W.R., and Forrest, J.T., 1973, Stratigraphy and paleogeography in the Murphy Marble belt: Amer. Jour. Sci., v. 273, p. 698-711.

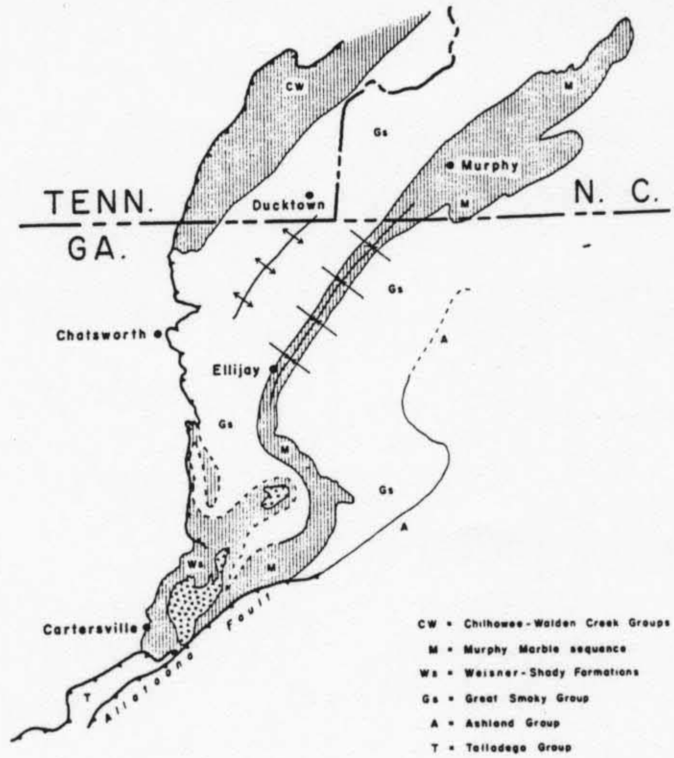

Figure 18. Structural and Stratigraphic relationships in north-central Georgia and southern Tennessee (from Hurst, 1973).

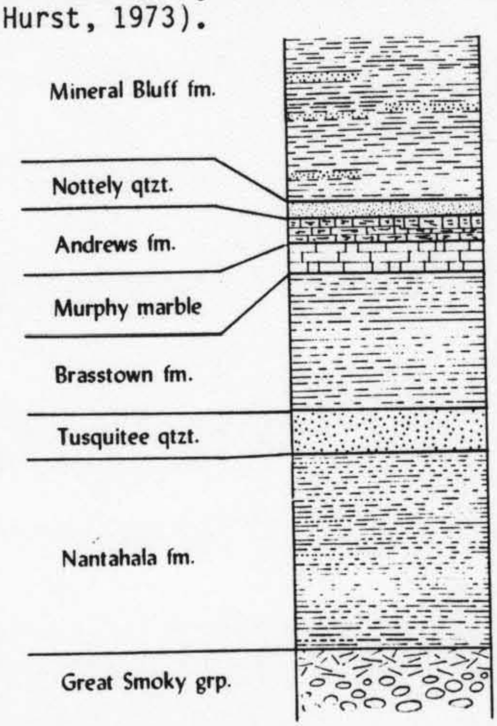

Figure 19. Stratigraphic column for rocks of the Murphy Marble Belt in western North Carolina and northern Georgia (from Power and Forrest, 1973).

DUCKTOWN MINING DISTRICT

The Ducktown mining district is located within the Blue Ridge province of Tennessee and Georgia (Fig. 20). Nine deposits of massive sulfide (total sulfide content approximately 65% of the rock) occur within highly folded and metamorphosed clastic sediments of the late Precambrian Great Smoky Group (Ocoee Series). The deposits range in size from 250,000 tons to more than 70 million tons, and together total more than 180 million tons with an average grade of 35.4% iron, 24.3% sulfur, 1.04% copper and 0.89% zinc, plus traces of lead, silver and gold. The mineralization consists of approximately 60% pyrrhotite, 30% pyrite, 4% chalcopyrite, 4% sphalerite, and 2% magnetite. The recorded history of the Ducktown district began in 1843 when a prospector panning for gold found native copper in a stream near the Burra ore body. Further discoveries of surface gossan outcrops quickly followed and by about 1855 all nine of the principal ore deposits within the district had been discovered. Production of both iron ore from the gossan and chalcocite from a supergene enriched zone began in 1847. Mining during the late 1800's produced copper from the primary sulfides through an open roasting process. This method, which required large quantities of timber to be cut for fuel, smelted the copper in open fires, which released vast amounts of sulfur dioxide gas into the atmosphere. The sulfur dioxide gas killed most of the remaining vegetation and left the soil vulnerable to erosion, which eventually created the barren appearance of the basin. Today, the Tennessee Chemical Company manufactures sulfuric acid, liquid sulfur dioxide, copper, copper chemicals, zinc concentrate and other products from ores of the Ducktown district.

Rocks of the district belong to the Great Smoky Group of the Precambrian Ocoee Series. The Great Smoky Group consists of coarse grained argillaceous feldspathic sandstone and graywacke interbedded with siltstone, shale and arkosic conglomerate. Rocks of the Blue Ridge were subjected to several periods of deformation and metamorphism during the Paleozoic. The structure of the Ducktown region is dominated by two major northeast-plunging folds--the Burra antiform and the Coletown synform (Fig. 20). Metamorphism in the Ducktown region is characterized by a typical Barrovian series, from chlorite grade in the western part to staurolite (-kyanite) grade in the eastern part.

Origin of the Deposits - The origin of the Ducktown deposits has been the subject of considerable debate. Initially, it was felt that the mineralization formed as the replacement of folded carbonate layers within the Great Smoky sequence by circulating hydrothermal fluids. Recent theories, however, favor a submarine exhalative origin, perhaps during the initial opening of the Iapetus (proto-Atlantic) ocean. The thick sequence of graywackes, sandstones, etc. (turbidite association) that host the massive sulfide mineralization, may have been deposited within a rift environment along the eastern margin of the North American continental plate as Iapetus began to open.

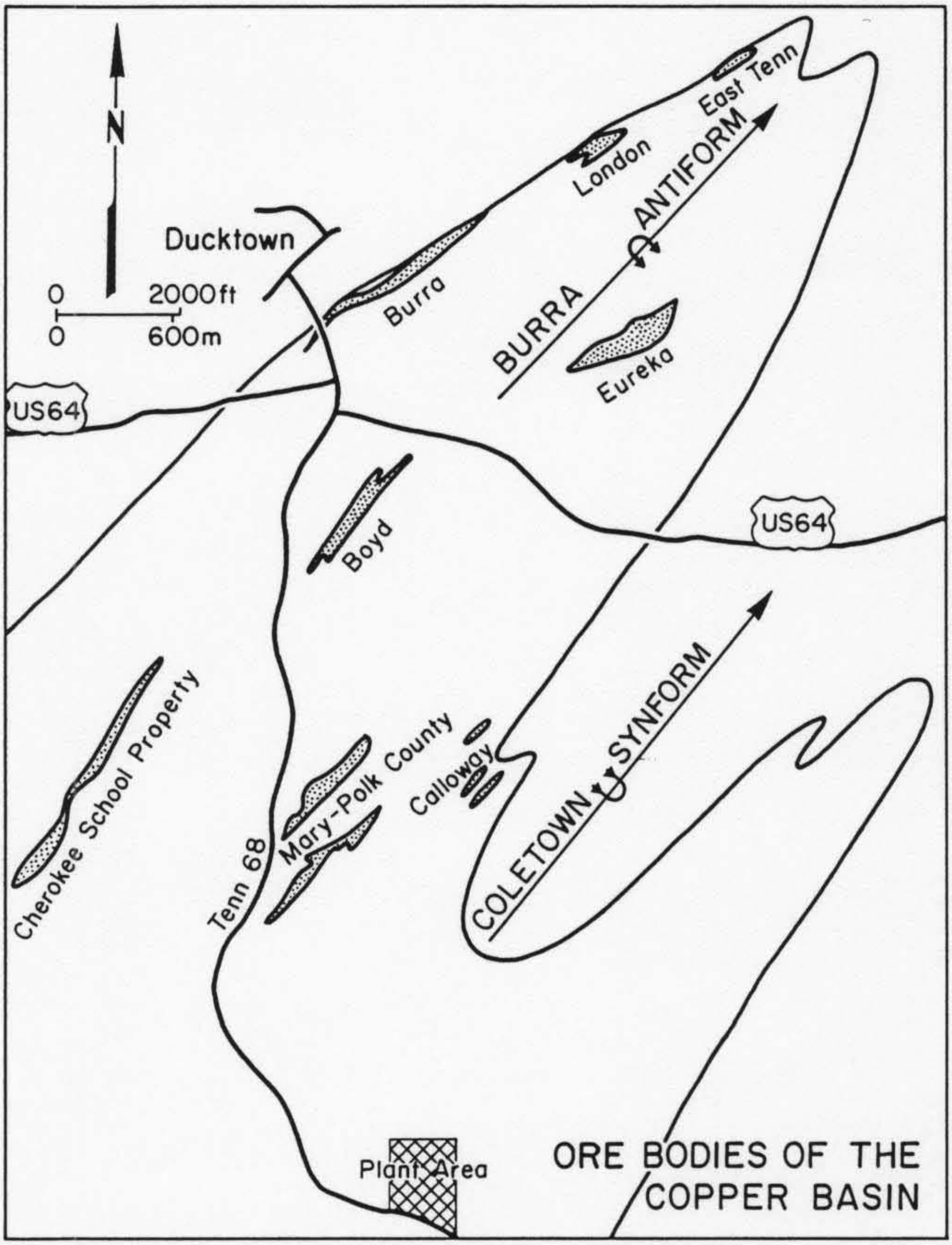

Figure 20. Map showing surface projections of ore bodies in the Copper Basin, Ducktown mining district, Tennessee (from Slater, et al., 1985).

References (Ducktown Mining District)

Emmons, W.H., and Laney, F.B., 1926, Geology and ore deposits of the Ducktown mining district, Tennessee: U.S. Geol. Survey Prof. Paper 139, 114 p.

Gair, J.E., 1982, The Blue Ridge massive sulfide model, in Exploration for Metallic Resources in the Southeast: Univ. of Georgia, p. 41-43.

Hutchinson, R.W., 1980, Massive base metal sulfide deposits as guides to tectonic evolution, in Strangway, D.W., (ed.), The Continental Crust and its Mineral Deposits: Geol. Assoc. of Canada Special Paper 20, p. 659-684.

Slater, W.R., 1982, Massive sulfide deposits of the Ducktown mining district, Tennessee, in Exploration for Metallic Resources in the Southeast: Univ. of Georgia, p. 91-99.

Slater, W.R., Misra, K.C., and Acker, C.P., II, 1985, Field Trip #5: Massive sulfide deposits of the Ducktown district, Tennessee, in Woodward, N.B., (ed.), Field Trips in the Southern Appalachians: Univ. Tenn. Dept. Geol. Sci., Studies in Geology 9, p. 171-190.

OCOEE GORGE (Ducktown to Parksville, Tennessee)

We will traverse this section of Blue Ridge rocks along the Ocoee River gorge from Ducktown to Parksville, Tennessee, at which point we will cross the trace of the Great Smoky thrust fault and again be in the Great Valley of the Ridge and Valley province.

Rocks within Ocoee Gorge exhibit considerable folding, faulting and variable metamorphism. The folds generally are overturned to the northwest, with axes trending northeast-southwest and axial planes that dip perhaps 30 degrees southeast. Except for the Great Smoky Thrust, faulting within the Gorge appears quite local, with minor displacements. The grade of metamorphism drops off gradually from staurolite grade in the Ducktown vicinity to only slightly metamorphosed sedimentary rocks in the Parksville vicinity (Fig. 21).

Rocks within the Gorge fall naturally into two groups: 1) those between Ducktown and the Sylco Creek fault, and 2) those between the Sylco Creek fault and the Parksville (Ocoee No. 1) Dam (Fig. 21). Although faulted and folded, the sequences of rocks generally "young" from southeast to northwest, the youngest being Chilhowee Group rocks along the northwest margin of the Great Smoky thrust sheet.

The oldest rocks in the section between Ducktown and the Sylco Creek fault are Great Smoky Group (Ocoee Series) metagraywacke, metaconglomerate, and mica schist. These rocks are overlain conformably by about 600 feet (183 meters) of dark pyritic phyllite and slate; and they in turn are overlain conformably by at least 1500 feet (457 m) of gray-green laminated phyllites with thin interbeds of quartzite and calcareous quartzite.

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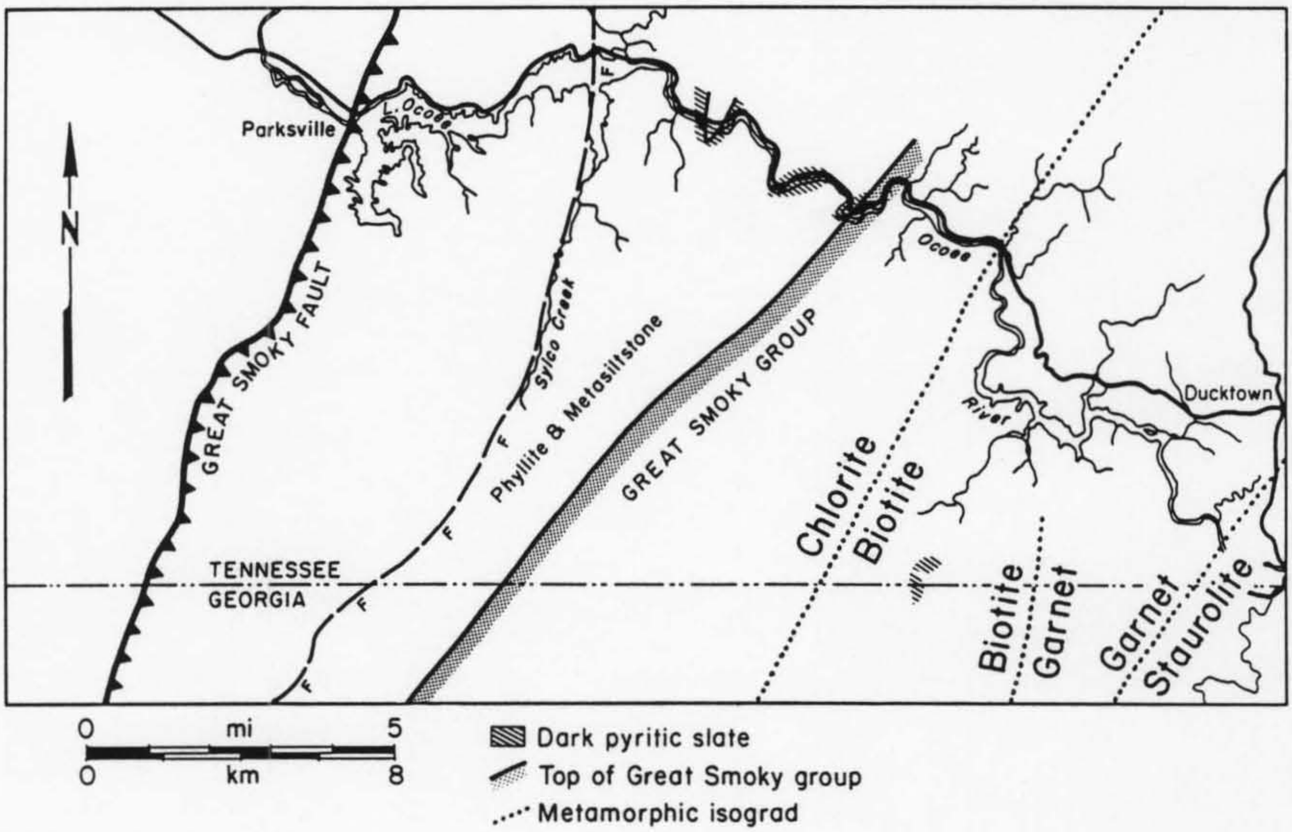

Figure 21. Distribution and metamorphic character of rocks in the Ocoee Gorge from Ducktown to Parksville, Tennessee (adapted from Hurst and Schlee, 1962).

- Day 5 -

Knoxville, Tennessee

to

Cumberland Falls, Kentucky

$\pm$ 200 miles (322 km)

Today will be spent largely within the Ridge and Valley province, crossing a transitional structural boundary with the Cumberland Plateau province sometime in the afternoon. In the morning, we will go underground in the Mascot-Jefferson City mining district. Following this, we will travel northwest across the Ridge and Valley province; traverse the Pine Mountain overthrust block; and pass into the Appalachian Plateaus province, ending the day at Cumberland Falls State Park where we will spend the night.

Major Stops

1. Geology and mineralization, Mascot-Jefferson City zinc district (figs. 22 and 23)

2. Thorn Hill section (Fig. 24)

3. Copper Creek thrust fault (Fig. 24)

4. Geology of the Pine Mountain overthrust block, (figs. 25 and 26) (Cumberland Gap, Lake City, Pine Mountain)

ZINC DEPOSITS OF THE MASCOT-JEFFERSON CITY DISTRICT, TENNESSEE

The first zinc mining in the Mascot-Jefferson City district, one of the leading producers of zinc in the U.S., commenced in 1854 at Jefferson City (then known as Mossy Creek). During its long mining history, many mines have been in operation for varying periods of time. Currently (1985), active mines in the district include the Coy, Young, New Market, and Immel mines operated by ASARCO; the Beaver Creek mine by Inspiration; and the Davis mine by the U.S. Steel Corporation.

The Mascot-Jefferson City district of east Tennessee is an important example of the carbonate-hosted (Mississippi Valley-type) Zn $\pm$ Pb deposits located in the Appalachian Ridge and Valley physiographic province. A series of northwest-directed thrusts in this area disrupted a thick sequence of Cambrian to Mississippian carbonate and clastic sedimentary rocks during the Allegheny orogeny (upper Paleozoic). Basement rocks apparently were not involved in the thrusting.

In east Tennessee, varying degrees of zinc mineralization (with or without lead) are found within carbonate units below the post-Knox unconformity that separates the Knox Group (Cambrian-Lower Ordovician) from the Chickamauga Group (Middle Ordovician). Significant mineralization is found over a narrow interval comprising the upper part of the Kingsport and the lower part of the Mascot formations. Almost all of the commercial ore occurs in a restricted stratigraphic interval that straddles the Kingsport-Mascot boundary; this interval comprises the U-bed, S-bed, R-bed (Kingsport) and the post-R or Q-bed (Mascot) (Fig. 22). The ore-bearing structures are complex bodies of "crackle" and "rubble" breccia of two different but related types (Fig. 23): (1) "breakthrough" structures that may cut through one or more stratigraphic horizons; and (2) "bedded" structures that are confined to certain limestone beds in the Kingsport Formation. The breakthrough breccias appear to be oriented, relatively narrow (a few meters to a few hundred meters in width) bodies, with lateral dimensions up to several thousand meters. Vertical thicknesses range to more than 490 feet (150 meters). These breccia bodies probably developed along nearly vertical pre-mineral faults and joints, but the picture has been obscurred by post-mineralization movements.

Important quantities of ore also are produced from bedded structures. A common type of bedded ore structure consists of finger-like lateral extensions of dolomitization, brecciation and mineralization (ore-matrix breccia) into limestone beds cut by breakthrough breccia bodies. Crackle breccia bodies occur along the top and lateral boundaries of large breccia bodies of both breakthrough and bedded types, and considerable ore occasionally is present within the crackle breccias.

Sphalerite is the principal ore mineral in the Mascot-Jefferson City district, and sparry dolomite is the main gangue mineral. The sphalerite in east Tennessee deposits typically is light-colored (honey yellow to light brown) and low in iron (usually less than 1% Fe). Traces of galena have been reported from several mines (e.g., Jefferson City, Immel), but the ores are galena-free for all practical purposes. Pyrite and marcasite are ubiquitous but minor constituents in both the host carbonate rocks and in the breccia bodies. Chalcopyrite is rare and has been reported in trace amounts only.

The age relationship between brecciation and zinc mineralization in the Mascot-Jefferson City district is complicated not only because there are various types of breccias, but also because there appears to have been more than one generation of brecciation and mineralization. Many geologists support the idea that the breccia bodies are solution-collapse features related to the post-Knox unconformity, and they consider the age of the main episode of mineralization to be later than this unconformity. A pre-Allegheny orogeny age for the mineralization is accepted by most workers in the area, based largely on the presence within some breccias of detrital sphalerite-bearing "dolomite sand bodies" with strikes and dips that parallel the regional strike and dip of the enclosing rocks.

From study of fluid inclusion within ore and gangue minerals, it is concluded that the deposits formed from warm, saline brines (temperature from 70-110 degrees Celcius; salinity about 20 wt% NaCl equivalent). Mixing of two fluids is suggested to have occurred during sulfide deposition--an evolved basinal brine moving into the breccia structures and mixing with a lower salinity fluid that was present within the host formations.

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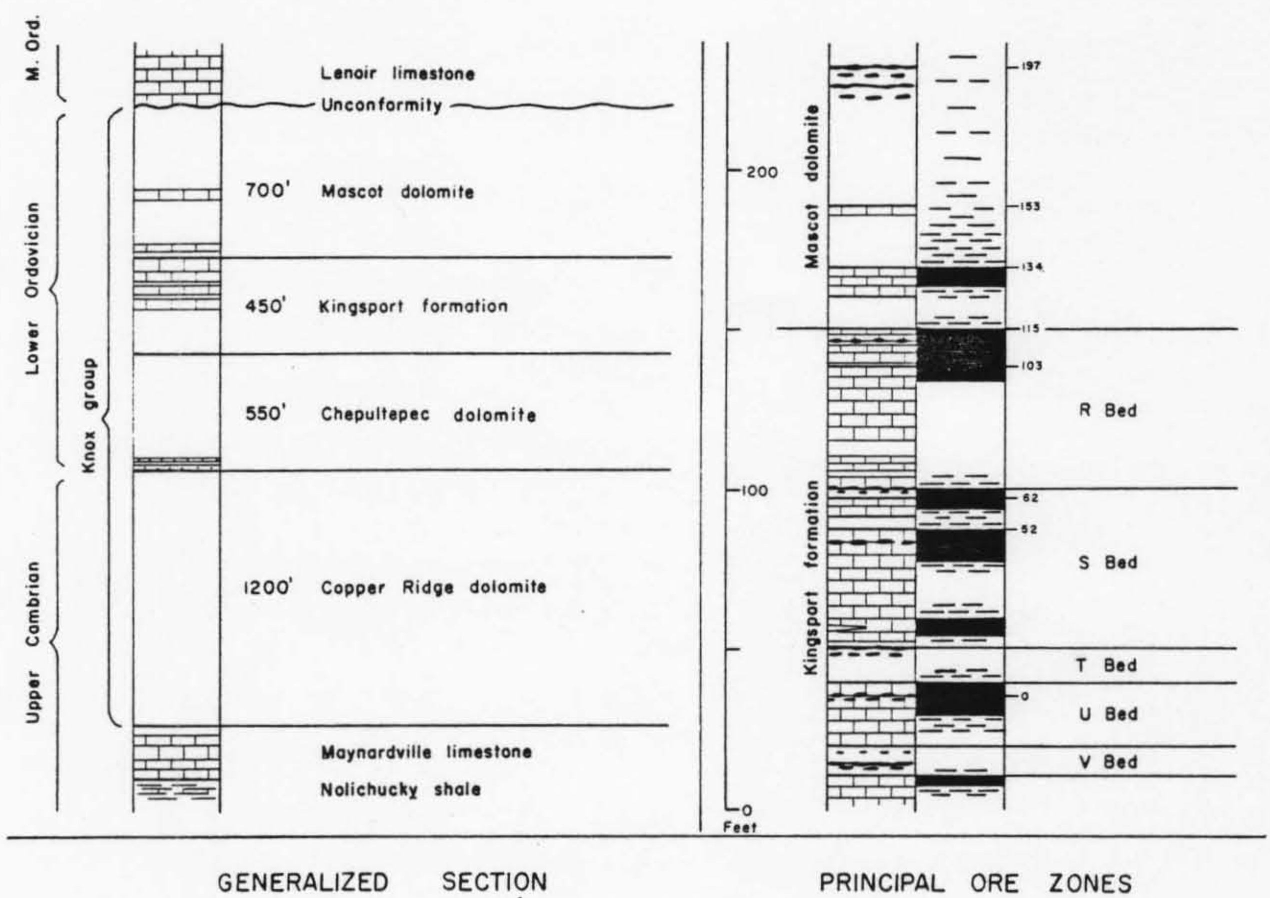

Figure 22. Generalized stratigraphic section and principal ore zones at the Jefferson City mine (From Crawford et al., 1969, Fig. 3).

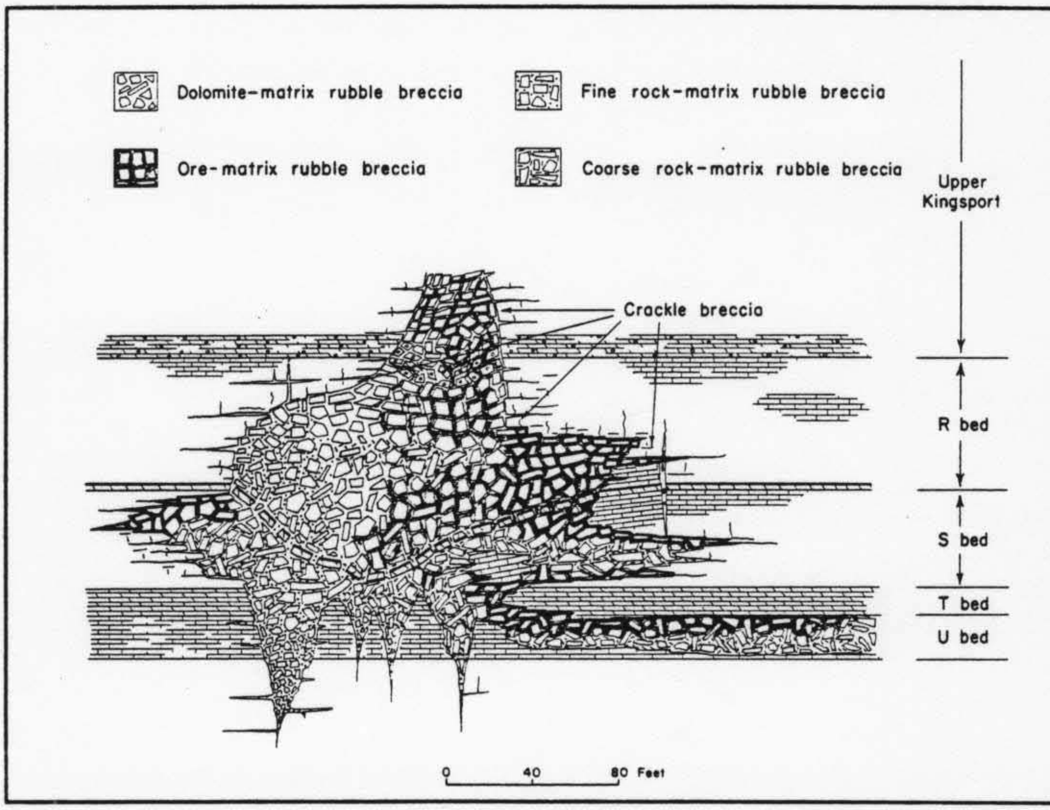

Figure 23. Generalized section through a portion of the Jefferson City mine showing the different types of breccias and breccia ore, including bedded breccia ore (from Crawford and Hoagland, 1968).

THORN HILL SECTION

One of the most complete and best exposed stratigraphic sections in the Ridge and Valley Province of the Southern Appalachians is the one in east Tennessee known as "The Thorn Hill Section". This excellent stratigraphic section was exposed during construction of "old" highway U.S. 25E. In 1977-78 the highway was rebuilt, mostly along a new route, which has provided better outcrops in deeper and fresher cuts. The new route is about one mile to the northeast of U.S. 25E and no longer goes through the village of Thorn Hill.

The Thorn Hill Section is sandwiched between two major thrust faults and begins with the Lower Cambrian Rome Formation and ends in the Early Mississippian Grainger Formation; it includes most units described in the southern Appalachians for this time interval. The units and their ages and thicknesses are shown in Table III.

Our encounter with the Thorn Hill section will begin at the Saltville Fault, where sandstones, siltstones, and shales of the Lower Mississippian Grainger Formation are overthrust by the Rome Formation. We will pass down through 3331 meters of section (Table III) to the Copper Creek Fault, where Lower Cambrian dolomites and shales of the Rome Formation are thrust over Middle Ordovician limestone of the Chickamauga Group. The stratigraphic displacement here is nearly 1.3 miles (2100 m).

The Copper Creek Fault is but one of numerous thrust faults in this section of the Southern Appalachians (Fig. 24). Thrusting from the southeast during the Alleghenian orogenic event produced several northeast-southwest-striking imbricate thrust sheets several hundred kilometers in length. The Copper Creek Fault can be traced for more than 280 miles (450 km) through the Ridge and Valley Province of Tennessee, Georgia and Virginia (Walker, 1985).

The Clinch Sandstone, which is present in the Thorn Hill Section, is one of the major ridge-builders in the Ridge and Valley. Earlier on this trip we crossed the Clinch at the Narrows, saw it on Pearis Mountain (Angels Rest), crossed it in a water gap in Walker Mountain, and again at the top of Draper Mountain. Here it is the principal ridge-forming unit at Clinch Mountain, which extends from northeastern Tennessee into southwestern Virginia, a distance of nearly 100 miles (161 km).

Table III

Ages and thicknesses of Stratigraphic Units in the Thorn Hill Section along U.S. Highway 25E (Modified from Walker, 1985).

Unit(s)	Age	Thickness (meters)
Grainger Fm. (top faulted)	Early Miss	149
Chattanooga Sh. Fm. Big Stone Gap Sh. Brailler Member Millboro Sh.	Late Dev.-E. Miss	266
Wildcat Valley Ss.	Early Dev	5
Clinch Fm. Poor Valley Ridge Ss. Hagen Sh.	Early Sil.	71
Juniata Fm.	Late Ord.	112
"Martinsburg" Fm.	Late Ord.	590
Moccasin Fm.	Late Ord.	192
Mid. Chickamauga Gr.	Mid. Ord.	187
Lower Chickamauga Gr.	Mid. Ord.	233
Upper Knox Group Mascot Dol. Kingsport Fm.	Early Ord.	276
Lower Knox Group Chepultepec Dol. Copper Ridge Dol.	Late Camb. (Early Ord.)	531
Conasauga Group Maynardville Ls. Nolichucky Sh. Maryville Ls. Rogersville Sh. Rutledge Ls. Pumpkin Valley Sh.	Mid. Camb.	592
Upper Rome Fm. (bottom faulted)	Early-Mid. Camb.	127
total thickness of Thorn Hill section		3331 meters

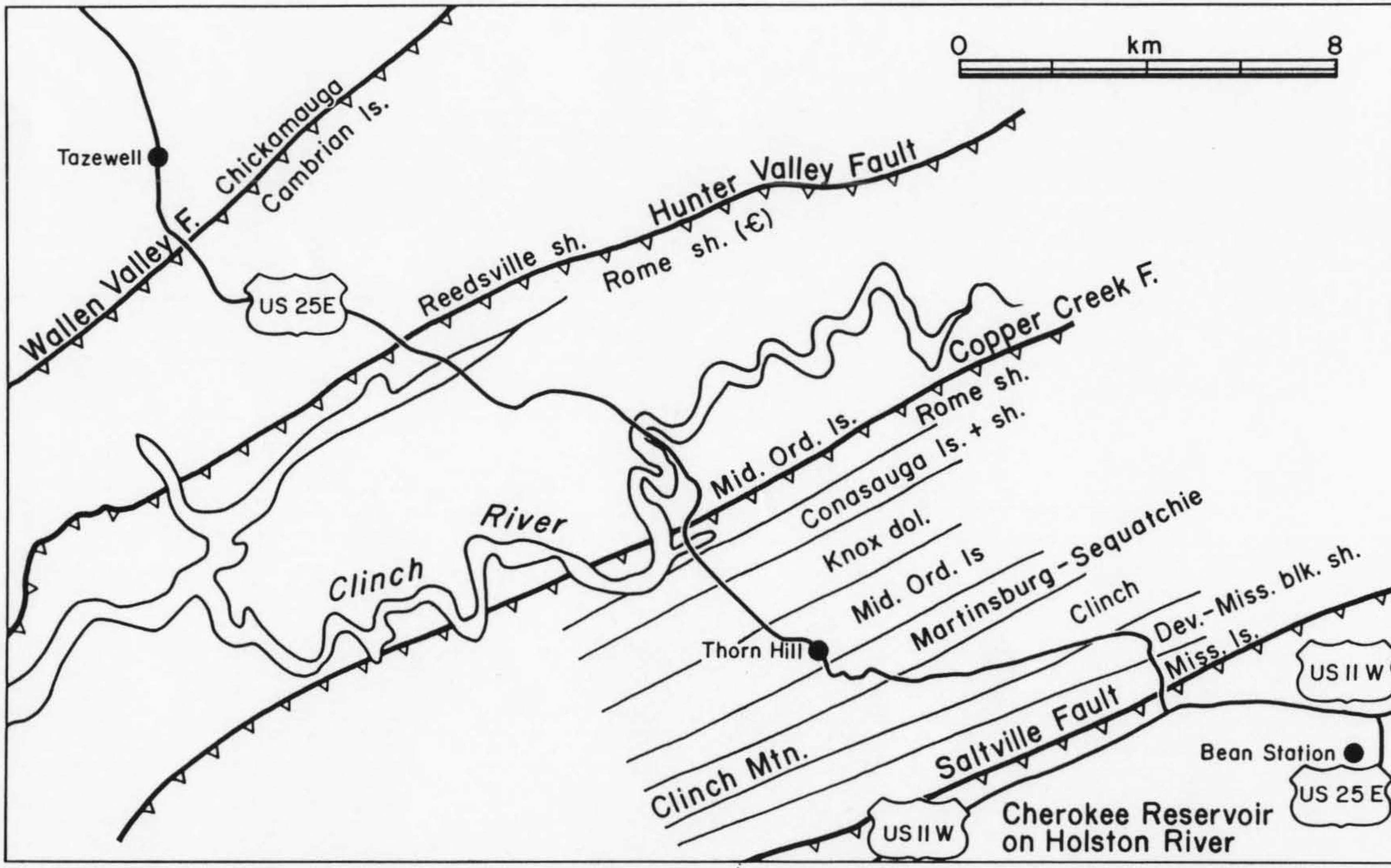

Figure 24. Thrust faults in the Ridge and Valley of northeastern Tennessee including the Thorn Hill Section.

References (Thorn Hill Section)

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PINE MOUNTAIN OVERTHRUST

The Pine Mountain thrust sheet along the northwest margin of the Ridge and Valley Province is one of the classic Appalachian geologic structures. It is a rectangular block about 125 miles (201 km) long and 25 miles (42 km) wide, encompassing parts of the states of Kentucky, Virginia and Tennessee. The block is bounded on the northwest by the Pine Mountain thrust fault, and on the southeast by the Clinchport thrust fault. The northeast and southwest margins of the block are marked by strike-slip (tear) faulting: the Russell Fork fault to the northeast and the Jacksboro fault to the southwest. Strata involved in the thrusting range from the Lower Cambrian Rome Formation to the Middle Pennsylvanian Bryson Formation. To the southwest of the thrust block, across Tennessee and into Georgia, thrusting dies out in an area of anticlines along the boundary between the Ridge and Valley and Appalachian Plateaus provinces (e.g., Sequatchie Valley anticline of Tennessee).

The general outline of the Pine Mountain structure is simple, but the internal details are complicated. The main part of the sheet is divisible into two gross structural units, the Middlesboro syncline and the Powell Valley anticline. Both are flat along their axes, and are passive structures formed in response to constraints imposed by the geometry of the underlying faults (Fig. 25). Structure within the Pine Mountain block largely is controlled by stratigraphy. Thrusting followed ductile shale layers, with faulting stepping ("ramping") up-section, westward, in the direction of tectonic transport. The most important shale units are the Rome Formation (Cambrian) and the Chattanooga Shale (Devonian). A general cross-section of the Pine Mountain block, showing ramping of the thrusting and the development of the Middlesboro syncline and Powell Valley anticline are given in Figure 25. Figure 26 illustrates the progressive evolution of the structures.

References (Pine Mountain Overthrust)

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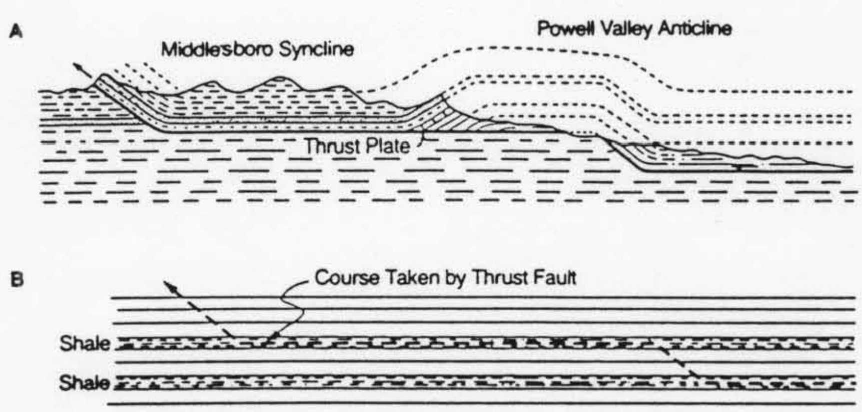

Figure 25. (A) Structure section of the Pine Mountain thrust; (B) path of faulting through the stratigraphic column, as seen before thrusting (from Rich, 1934).

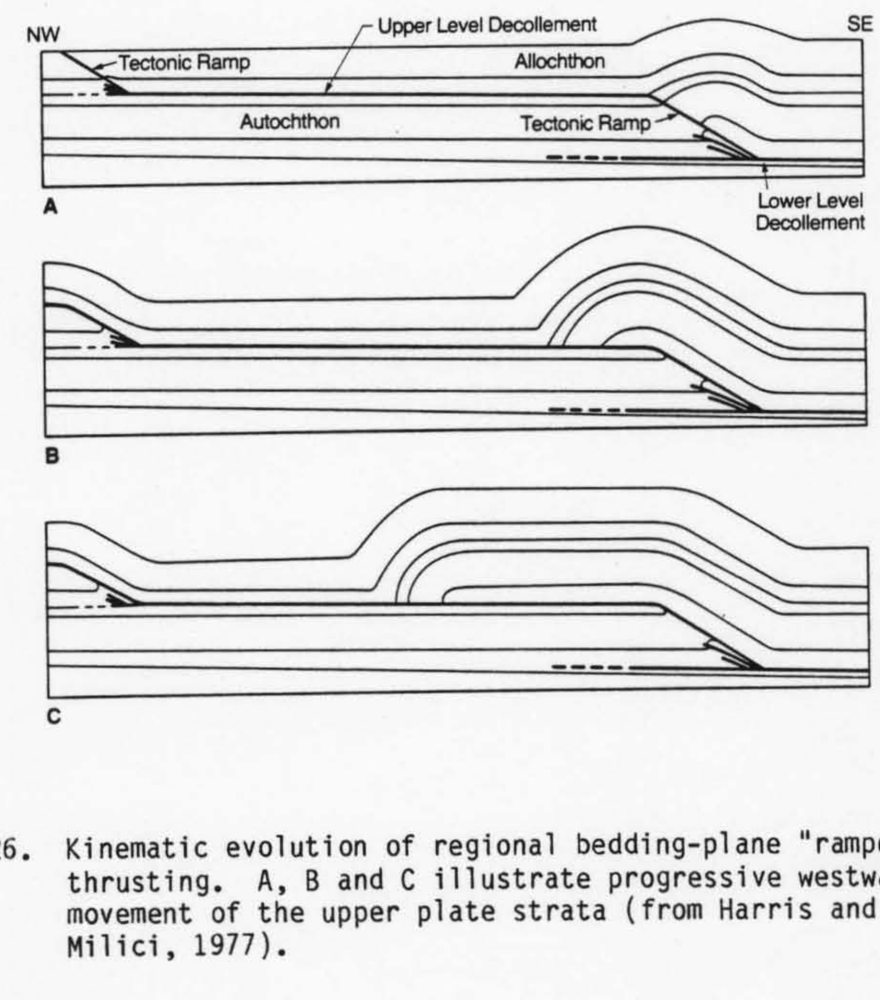

Figure 26. Kinematic evolution of regional bedding-plane "ramped" thrusting. A, B and C illustrate progressive westward movement of the upper plate strata (from Harris and Milici, 1977).

Day 6

Cumberland Falls, Kentucky

to

Columbus, Ohio

± 280 miles (451 km)

Our day will begin in Pennsylvanian rocks of the Cumberland Plateau. Excellent exposures of these rocks, which showcase the complex alluvial plain-deltaic depositional environments that characterize Pennsylvanian strata in this region, are present in deep roadcuts along Interstate Highway 75. We will pass fairly quickly through relatively thin sections of Mississippian, Devonian, and Silurian rocks, passing out of the Cumberland Plateau and into the Interior Low Plateaus Province. Part of the day will be spent on Ordovician rocks of the "Bluegrass region" of Kentucky. We will examine some of the highly fossiliferous Ordovician (Cincinnatian) rocks for which this area is so well known before returning to Columbus.

Major stops

1. Cumberland Falls

2. Pennsylvanian stratigraphy along I-75 (Table IV, figs. 27 and 28)

3. Pennsylvanian/Mississippian unconformity at Mt. Vernon

4. Kentucky River fault zone (Fig. 29)

5. Fossiliferous Ordovician strata, Maysville, Kentucky (Table V, Fig. 30)

6. Columbus, Ohio

CARBONIFEROUS STRATIGRAPHY

Interpretations of roadcuts through these Pennsylvanian Age deposits have centered on their comparison with present-day alluvial plain-deltaic environments such as are being formed in the Mississippian River delta area today. Figures 27 and 28 give plan and cross-sectional views of the strata in eastern Kentucky and Table IV relates the rock types to the depositional environments.

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Cressman, E.R., 1981, Surface geology of the Jeptha Knob cryptoexplosion structure, Shelby County, Kentucky: U.S. Geol. Surv. Prof. Paper 1151-B, 16 P.

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Table IV.
Lithologic description of facies and their interpreted despositional environments (Modified from Ferm, et al., 1971).

DEPOSITIONAL ENVIRONMENT	DESCRIPTION OF FACIES
1.0 Lower Alluvial Plain to Upper Delta Plain	
1.1 Meandering Channels	Massive thick sandstones with point-bar structures and wedge-to trough-type large scale cross-beds with erosional basal contacts. Plant and wood fragments. Grain size and bedding thickness decreases upward. Shale plugs.
1.2 Levee and crevasse-splay	Alternative thin-beds of mudstone and fine-grained sandstone to siltstone with ripple bedding, root-disrupted parallel laminations, and plant fragments.
1.3 Swamp	Coal. Carbonaceous clay in well-drained swamps. Peat in poorly drained swamps. Pyrite.
1.4 Lake	Limestone alternating with dark-gray calcareous shale. Spirorbis (worm tubes, usually on other fossils), fish parts, and ostracodes are most common fossils.
2.0 Lower Delta Plain	
2.1 Distributary channels	Massive sandstone with dune and ripple structures. Basal scour. Abandoned channel deposits of siltstone and dark-gray shale with abundant plant fragments. Siderite and ironstone concretions.
2.2 Levee and crevasse-splay	Alternating thin-beds of siltstone and mudstone with plant fragments, disrupted parallel laminations, and ripple bedding. Iron oxide concretions.
2.3 Swamp	Coal, pyrite, claystone-siltstone partings.
2.4 Lake interdistributary bay, and interdelta bay	Shale, ironstone concretions, plant fragments. Limestones with ostracodes, Spirorbis and fish scales.

Table IV. (Con't)

DEPOSITIONAL ENVIRONMENT	DESCRIPTION OF FACIES
2.5 Beach	Thin siltstone and fine-grained sandstone beds.
3.0 Delta-front distributary-mouth bars	Alternating thin beds of siltstone, fine-grained sandstone and shale (mudstone) with gradational basal contact. Slightly arched beddings reflecting bar shape. Ripple, dune, and parallel bedding with burrow-mottled structures, especially at distal fringe.
4.0 Prodelta	Laminated silty shale and massive sandstone.
5.0 Bay	Mudstone and shale, dark-gray to reddish-gray. Limestones, with brackish fossils.

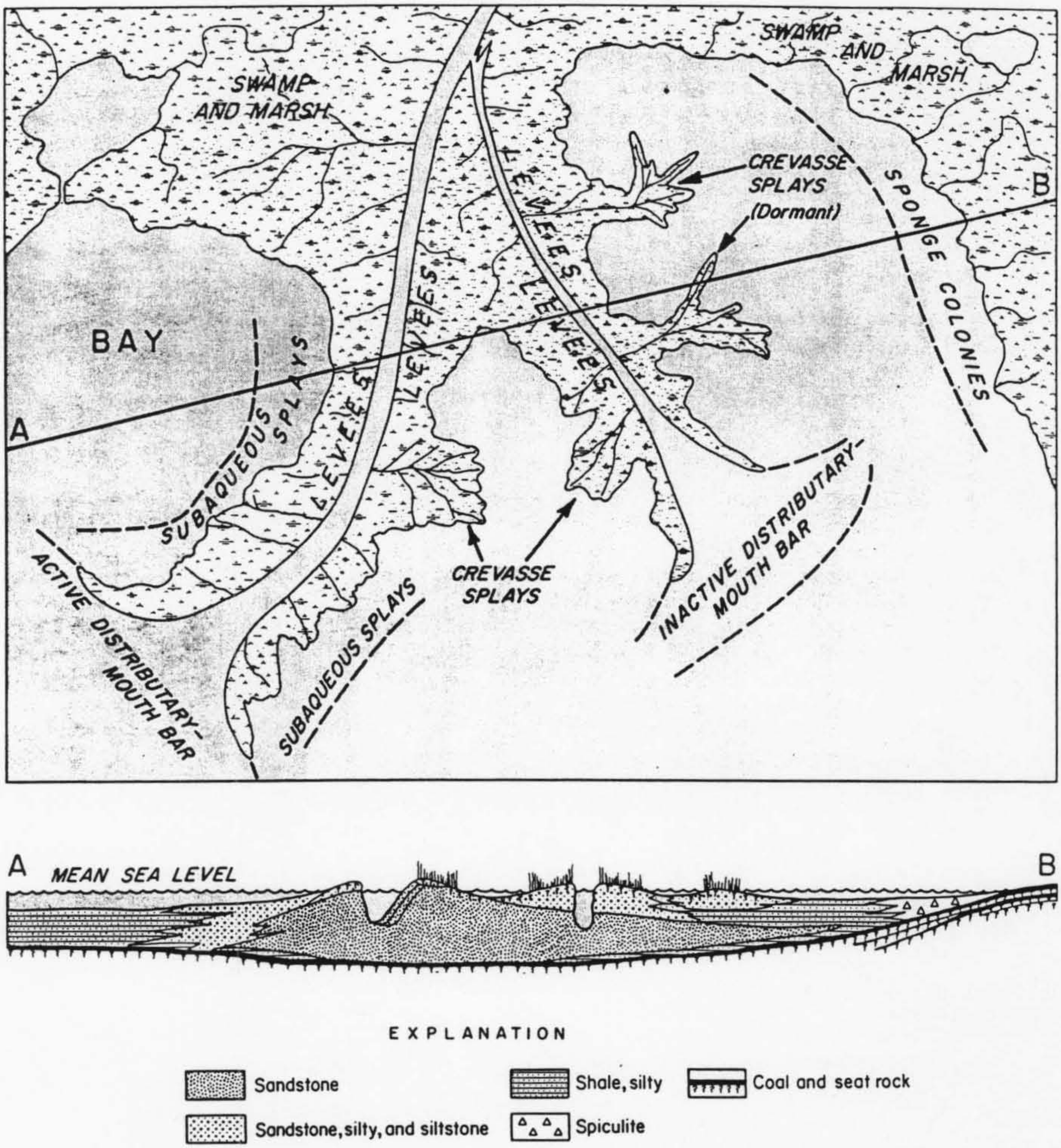

Figure 27. Upper delta-plain model. (Modified from Ferm et al., 1971).

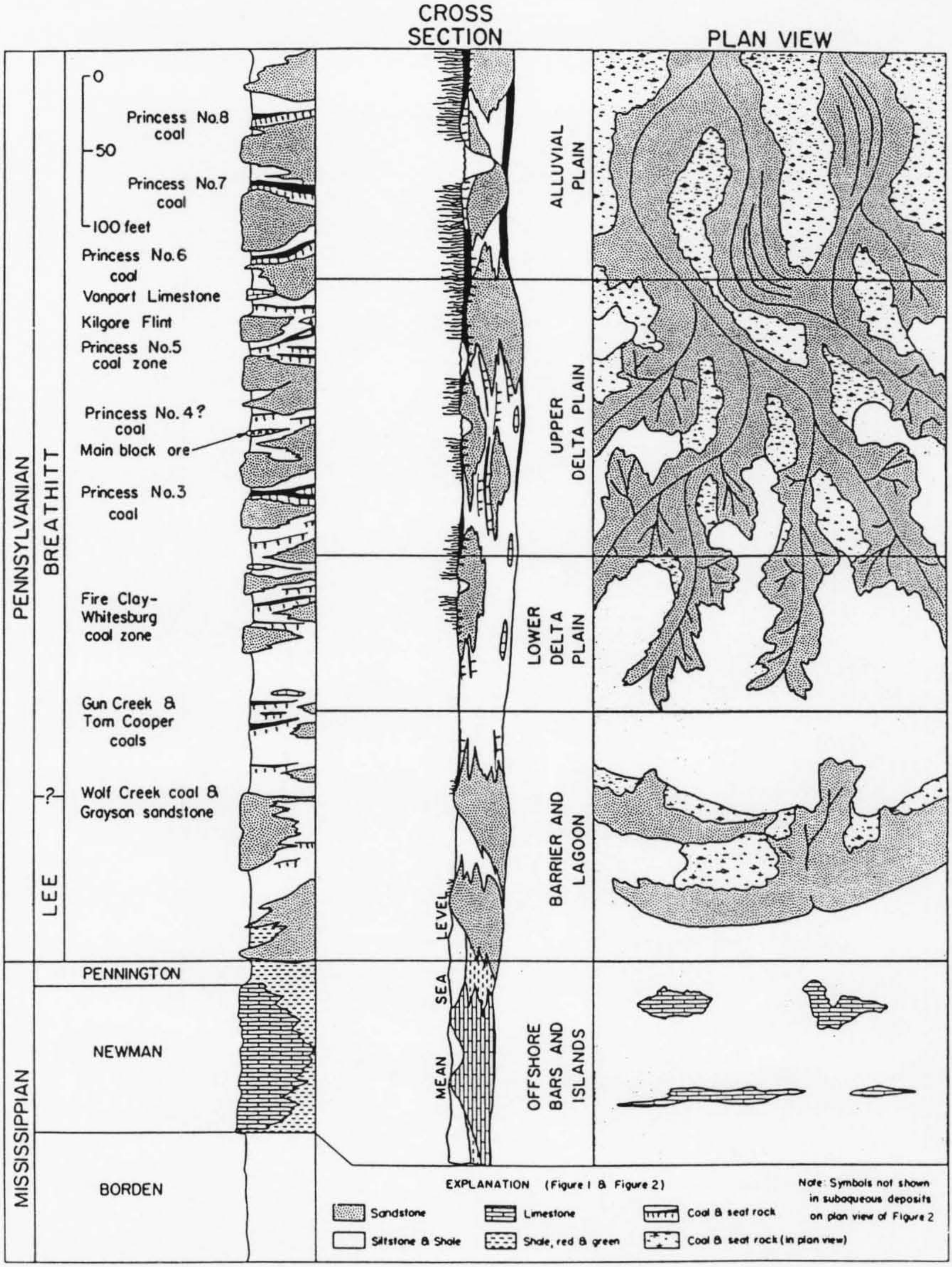

Figure 28. Paleoenvironmental interpretation of Carboniferous rocks. (From Ferm et al., 1971).

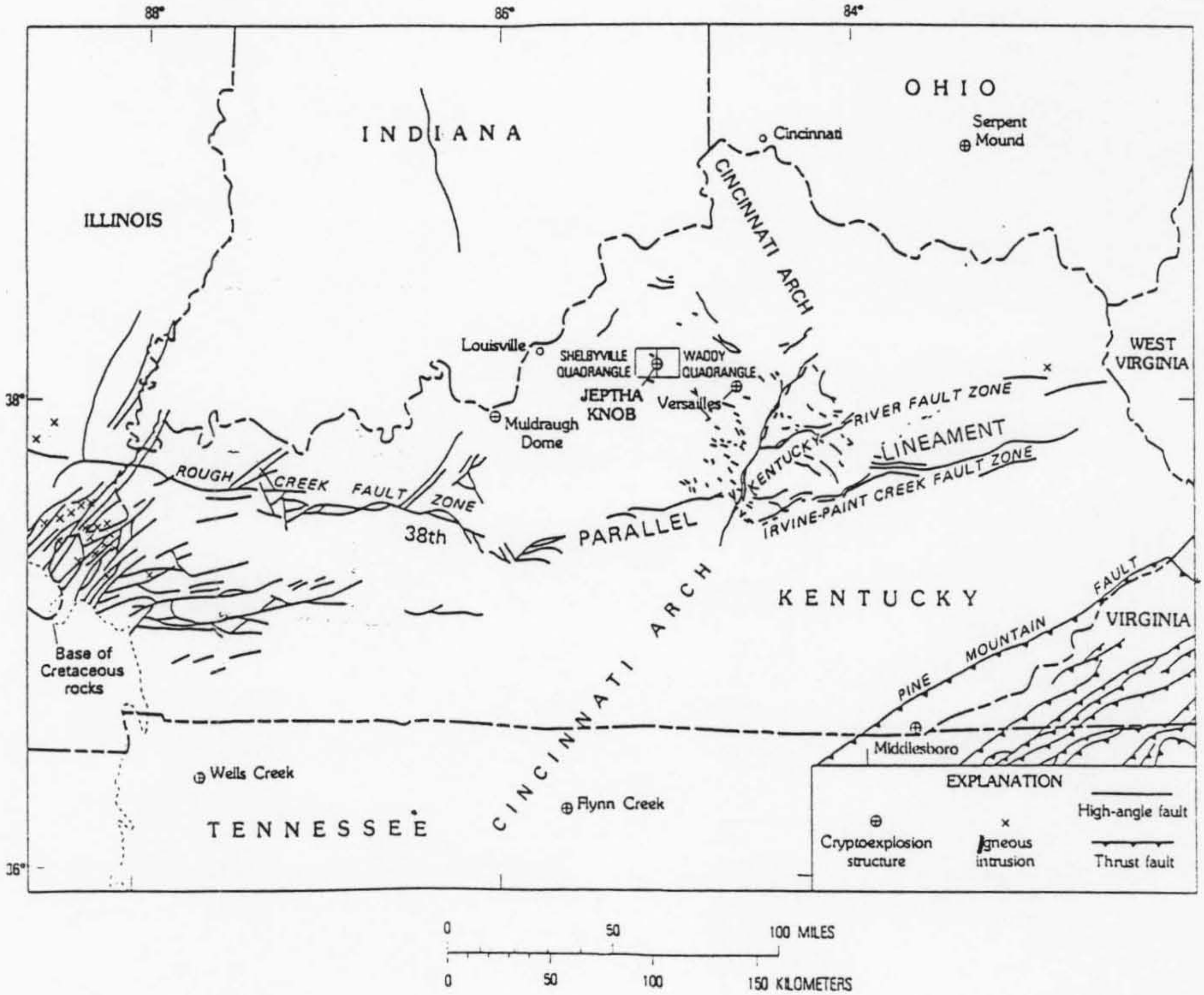

Figure 29. Structural features of Kentucky. (Cressman, 1981).

LEXINGTON PLAIN -- BLUEGRASS SECTION

The Lexington Plain section of the Interior Low Plateaus province typically is a rolling upland with fertile soil that is residual from solution of the underlying Ordovician limestones. Karst topography is developed to some extent in the area. Three sections of the Bluegrass section are recognized (Fig. 30).

The Inner Bluegrass is the central division, in which Lexington, Kentucky is situated. It is underlain by Middle Ordovician limestones. It is a gently rolling plain, broken by mature topography near large streams and in areas where the rocks are shaly. We enter it first at the Kentucky River.

The Eden Shale Belt, surrounding the Inner Bluegrass area, is a rough, hilly belt, underlain by the Upper Ordovician Eden Formation. This unit, which overlies the limestones of the inner division, is dominantly shale. The topography produced by stream erosion is angular and mature. Valleys are narrow, and the divides separating them are narrow and winding.

The Outer Bluegrass. Rocks above the Eden shale contain more limestone than the Eden, and thus the Outer Bluegrass belt is much like the Inner Bluegrass. The topography is somewhat rougher, because the rocks contain more shale than the Middle Ordovician limestones, but it is not as rough as the Eden shale belt.

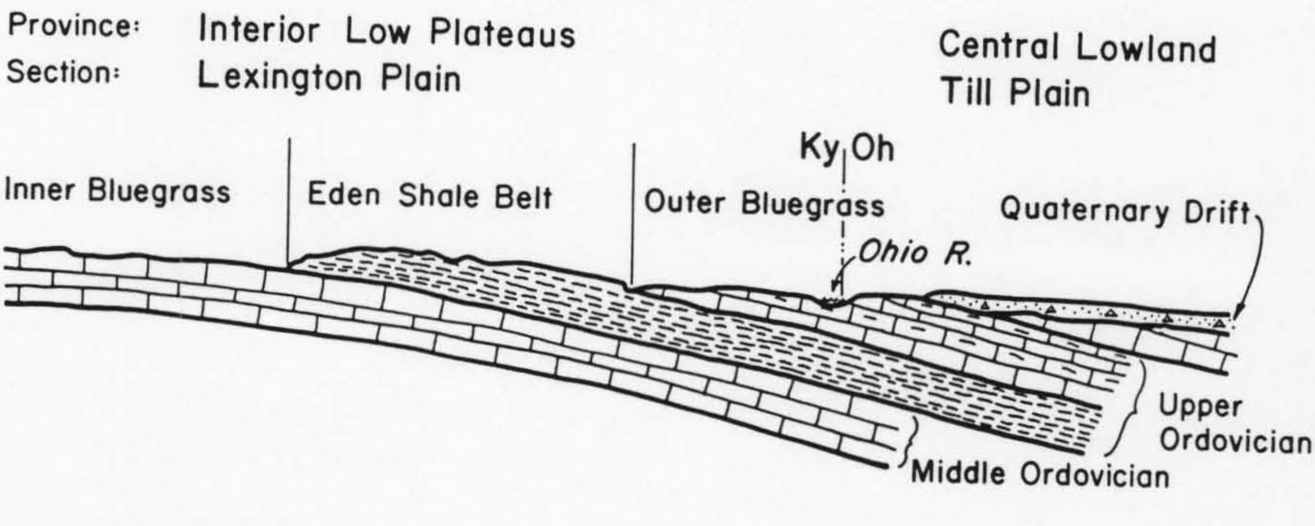

Figure 30. Physiographic areas of the Bluegrass Region.

ORDOVICIAN FOSSILS

The Ordovician rocks in the northern Kentucky - southwestern Ohio region are among the world's most fossiliferous, and have attracted much geological/paleontological attention for more than 125 years. The resulting nomenclature is complicated and much progress has been made in recent years in defining recognizable rock units, testing them by mapping a series of quadrangles along the Ohio River, and working out the fossil sequence using conodonts and other fossils. Table V shows the stratigraphic relationships of the formations in the area (Sweet, 1979). Fossils found in the section where we will stop include brachiopods: *Platystrophia ponderosa*, *Strophomena*, *Onniella*, *Rafinesquina fracta*, *Zygospira modesta*; tribolites *Cryptolithus tesselatus* and *Flexicalymene meeki*; graptolites (*Climacograptus typicalus*); mollusks, echinoderms and many bryozoans. For details on the Upper Ordovician stratigraphy see Figure 31.

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Sweet, W.C., 1979, Conodonts and conodont biostratigraphy of the post-Tyrone Ordovician rocks of the Cincinnati region, *in* contributions to the Ordovician paleontology of Kentucky and nearby states: U.S. Geol. Surv. Prof. Paper 1066-G, p. G1-626.

Table V. Stratigraphy at Maysville

Group	Formation
RICHMOND	Preachersville m. of Drakes Fm.; sh. & slst.) Bull Fork Fm.; gray sh. with thin foss. lss.) not seen
MAYSVILLE	Grant Lake Fm.; thin-bdd. rubbly ls., sh. partings ± 100'; Fairview Fm.; thin- to med-bdd. foss. ls., sh. partings up to 10" thick; flow rolls, ripple marks, 70-110' *Strophomena planoconvexa* zone, ± 3' thick, near base
EDEN	Kope Fm.; gray silty calc. sh., thin lenticular compact foss. lss., 200-230'; exposed in sections near the Pepsi-Cola Warehouse.

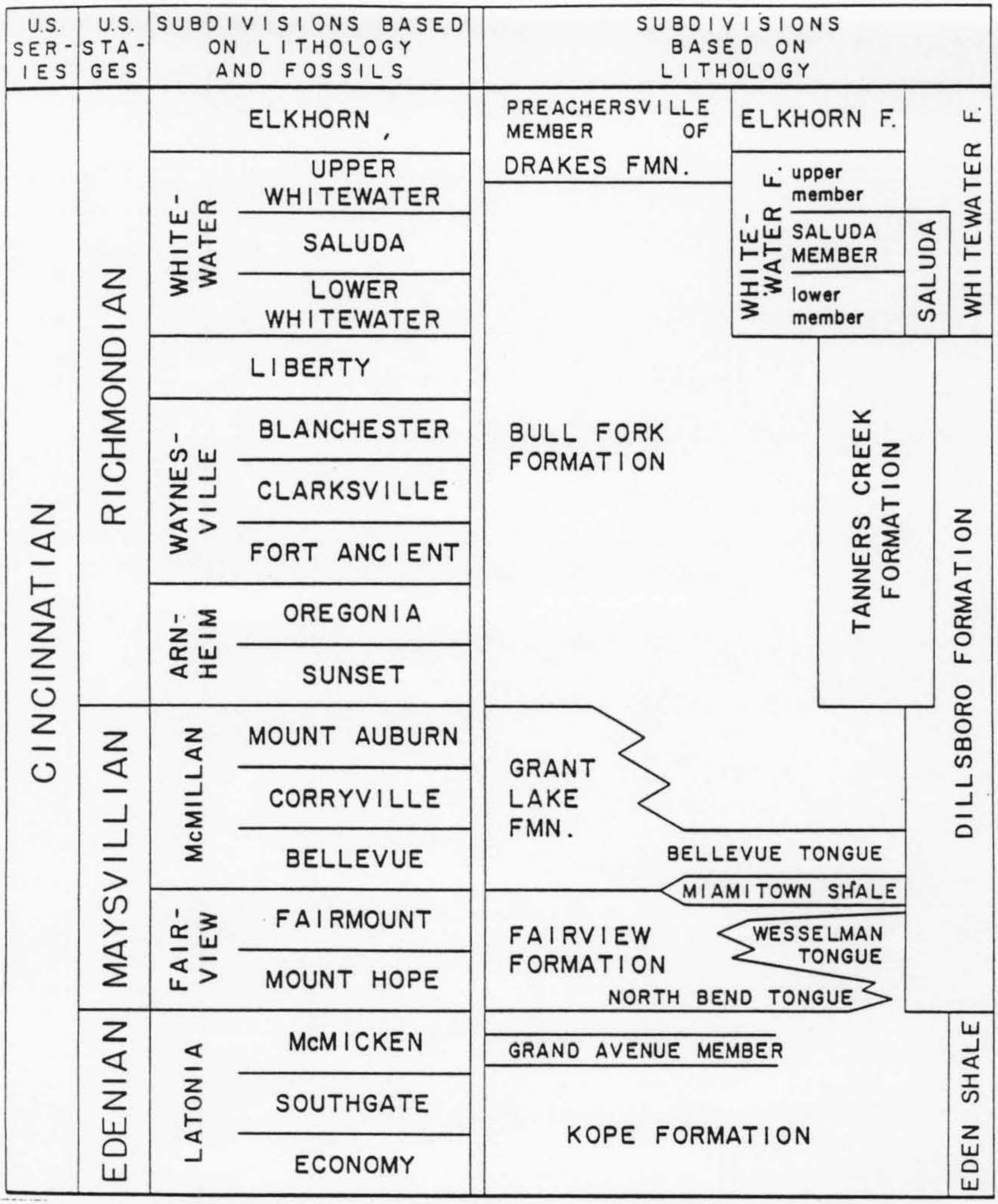

Figure 31. Stratigraphy in the Maysville area. The relationship of stratigraphic names that have been applied to rocks in the Indiana, Kentucky and Ohio areas is shown on the right side of the diagram. These names do not necessarily represent different rock units or their lateral relationships. Data derived from: Caster, et al. (1955/61), Anstey and Fowler (1969), Brown and Lineback (1966), Ford (1967, 1974), Gray (1972), Hatfield (1968), Hay, et al. (1981), Martin (1975), Peck (1966), and Ross, et al. (1982) (Reprinted from Davis, 1981).